1-1-1984

Coastal Geology of Winthrop, MA

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INTRODUCTION

The Winthrop shoreline, which is comprised of open ocean beaches and protected harbor environments, has been studied by several members of the Coastal Environmental Research Group, Boston University. The results of these investigations are reported in two Masters theses (Levin, 1981; Sullivan, 1982) and in a number of publications (FitzGerald, 1980, 1981; FitzGerald et al., 1981; Levin and FitzGerald, 1981). This paper is a compilation of these works.

Winthrop's 7.5km eastward facing coast encompasses Winthrop Beach to the north and Yirrell Beach to the south (Fig. 1). This stretch of shoreline contains numerous engineering structures and thus presents an excellent opportunity to determine the influence of different types of coastal structures on beach processes. The sand and gravel composition of the Winthrop beaches also provides a means of assessing sediment transport under varying energy conditions. Many of the sediment transport patterns that are reported in this paper were a result of the February Blizzard of 1978, the largest storm to affect this region in 50 years.

PHYSICAL SETTING

The Town of Winthrop is a peninsula forming the northeast boundary of Boston Harbor (Fig. 2). Like much of the surrounding region its topography is dominated by drumlins that have been connected by sand and gravel spits (Johnson, 1919) (Fig. 3). Beaches consist of moderately-sorted sand with local concentrations of gravel. The gravel content of the beaches increases toward the drumlin headlands and in an offshore direction.

The entire shoreline in this area is backed by seawalls of various construction except for a small section of beach south of Point Shirley (Fig. 1). Other coastal structures along the Winthrop shore include five groins, two pedestrian ramps and five closely spaced offshore breakwaters.

The region has a mean tidal range of 2.8m increasing to 3.3m during spring tides. Seasonal wave energy fluxes for this part of the coast are shown in Figure 4. Maximum wave energy occurs during the fall and is smallest during the summer. The dominant wave approach is from the east-northeast, a condition prevalent during northeast storms. The highly irregular nearshore and offshore

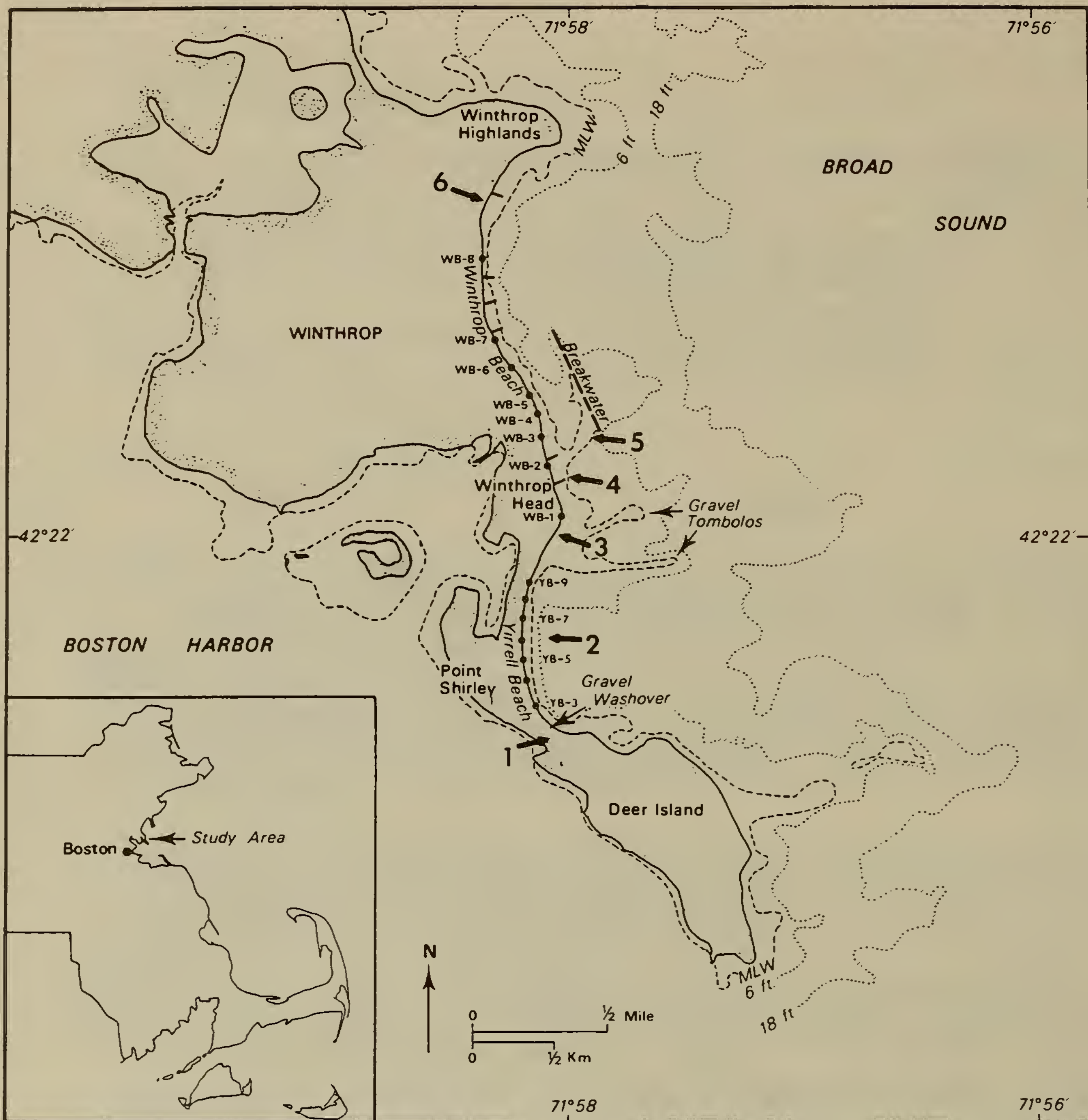


Figure 1. Location Map and fieldtrip stops.

Figure 2. 1978 Vertical aerial photograph.

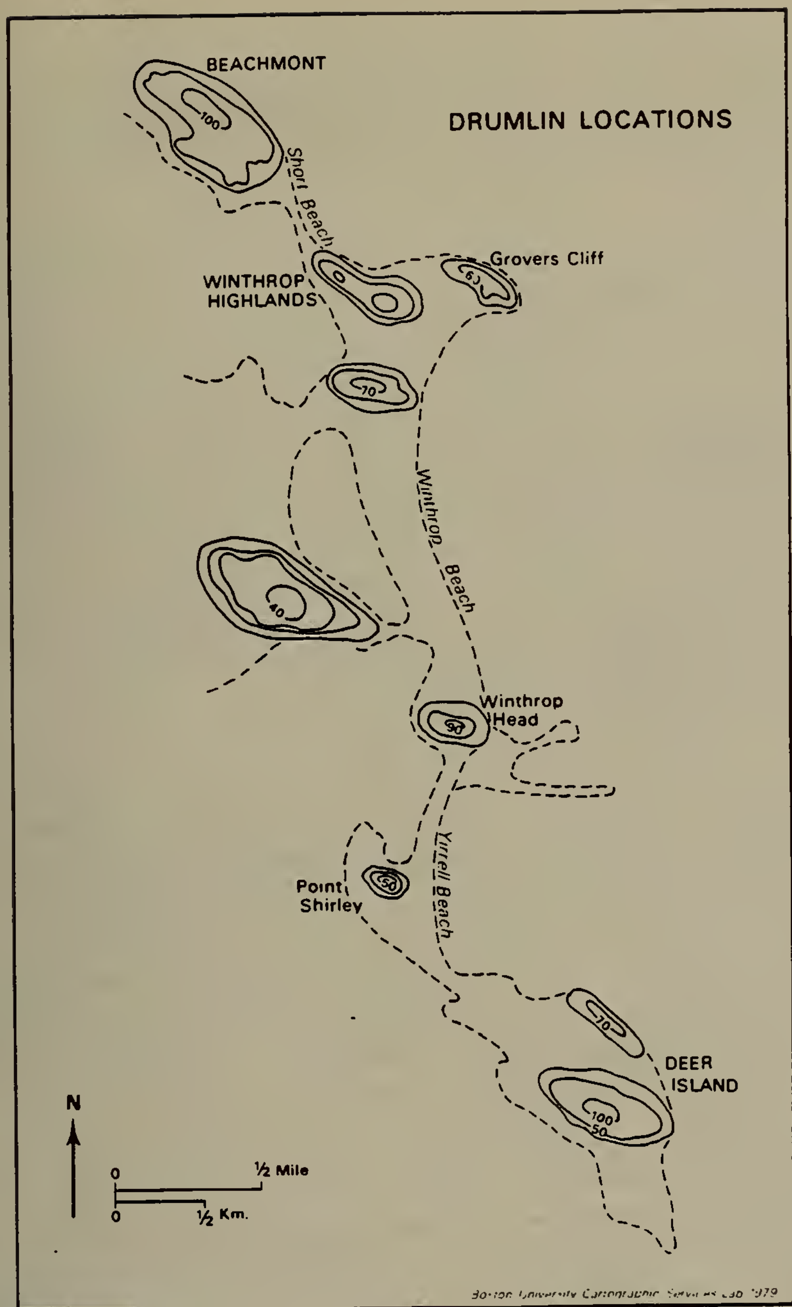


Figure 3. Location and height of Winthrop area drumlins.

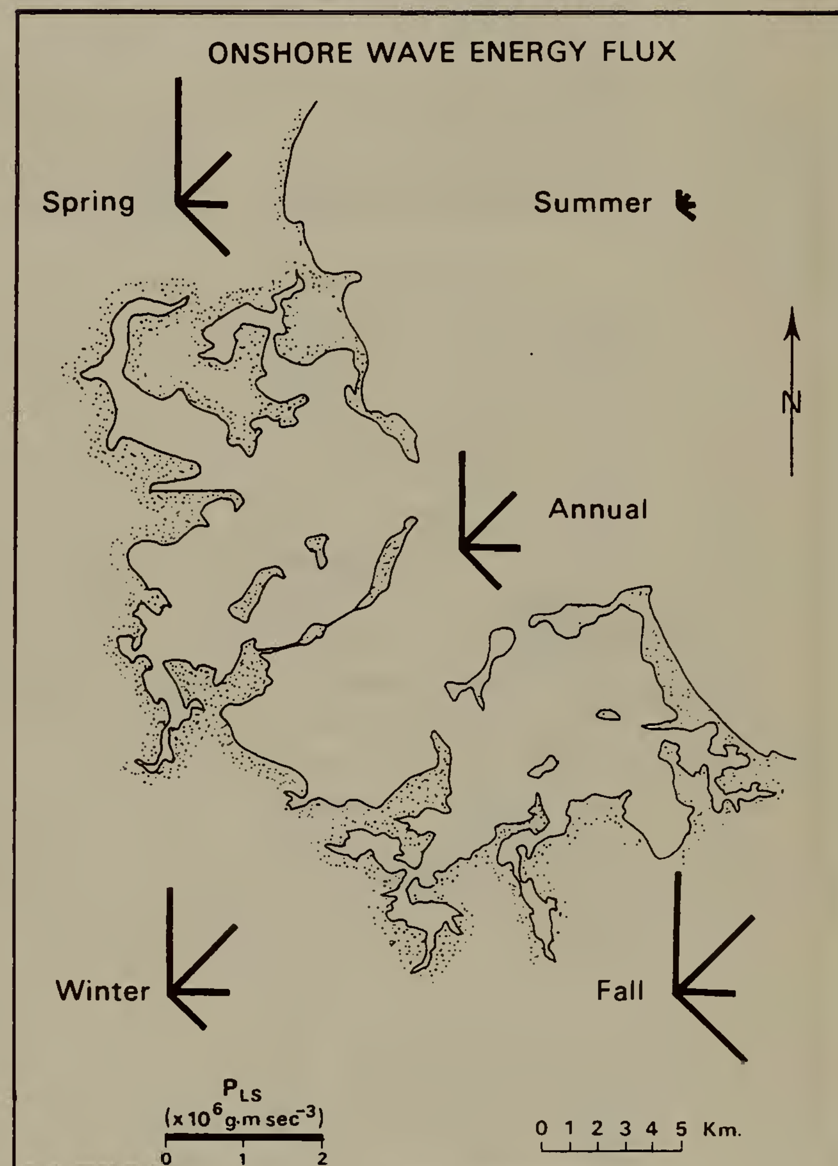


Figure 4. Wave energy fluxes determined from SSMO data.

Figure 5. 1739 Historical sketch of the Winthrop and Revere shorelines.

bathymetry coupled with the presence of numerous coastal structures produce complicated and variable patterns of littoral transport.

SHIRLEY GUT (Stop #1)

As seen in the historical map in Figure 5 the region between Point Shirley and Deer Island was once the site of a tidal inlet known as Shirley Gut. Evidence of the former inlet is seen in the fathometer profiles taken offshore of Yirrell Beach (Fig. 6). Note that the two seaward profiles contain a 2 to 3m scarp adjacent to Deer Island. This bank was likely cut by ebb tidal currents issuing out of the inlet. Evidence of the inlet channel along the inner profiles is probably masked by a sediment cover.

Shirley Gut closed in 1934. Leading to that time the inlet had gradually shoaled and narrowed due to spit growth on both sides of the inlet. Cross sectional changes of the channel and historical changes of the inlet shoreline are depicted in Figures 7 and 8. It is likely that the inlet closed as a result of storm processes (Fig. 9). Under normal conditions the inlet was probably stable because tidal scour would have been sufficient to erode any sediment dumped into the channel by wave-generated currents. However, during storms larger waves would have dramatically increased the transport of sediment toward the inlet along Point Shirley and Deer Island. Although some of this sediment would have been removed by the strong tidal currents accompaning the storm surge, much of the sediment would have remained. The reason for this is that during storms most of the increased flow into and out of Boston Harbor was accomodated through the much larger Presidents Roads channel. Thus, Shirley Gut was gradually filled in during storms due to a greater amount of sediment being delivered to the inlet than the volume of sediment that could be removed by the tidal currents.

Another factor that contributed to the closure of the inlet was its location at the center of the embayment. At this site, sediment was transported toward the inlet from both longshore directions. Note that the orthogonals in the wave refraction diagram in Figure 10 show that northeast storm waves would move sediment toward the former Shirley Gut location. This pattern of sedimentation has persisted to the present time as evidenced by the large gravel washover that was deposited in this region during the February Blizzard of 1978 (Fig. 11, Location A). The gravel consisted of well rounded cobble-sized material and was deposited over a previous gravel ridge and washover complex. The source of the gravel is believed to have come from the intertidal gravel terrace next to Deer Island (Fig. 11, Location B). Although offshore gravel may have been a possible source, a grain size distribution map of the region (Fig. 12) indicates that the sediment seaward of washover area is almost entirely sand.

The washover was mapped by a theodolite survey and seven beach profiles (Fig. 13). Its topography was ridge like, which is typical morphology of post storm gravel beaches (Lewis, 1931). The deposit measured 200m long, 50-60m wide and 70-80cm thick. Its depth was determined from three trenches dug along profile SP-6 (Fig. 14). The bottom of washover was estimated by the presence of dead weeds in growth position, a layer of oxidized gravel and concentrations of wood and debris.

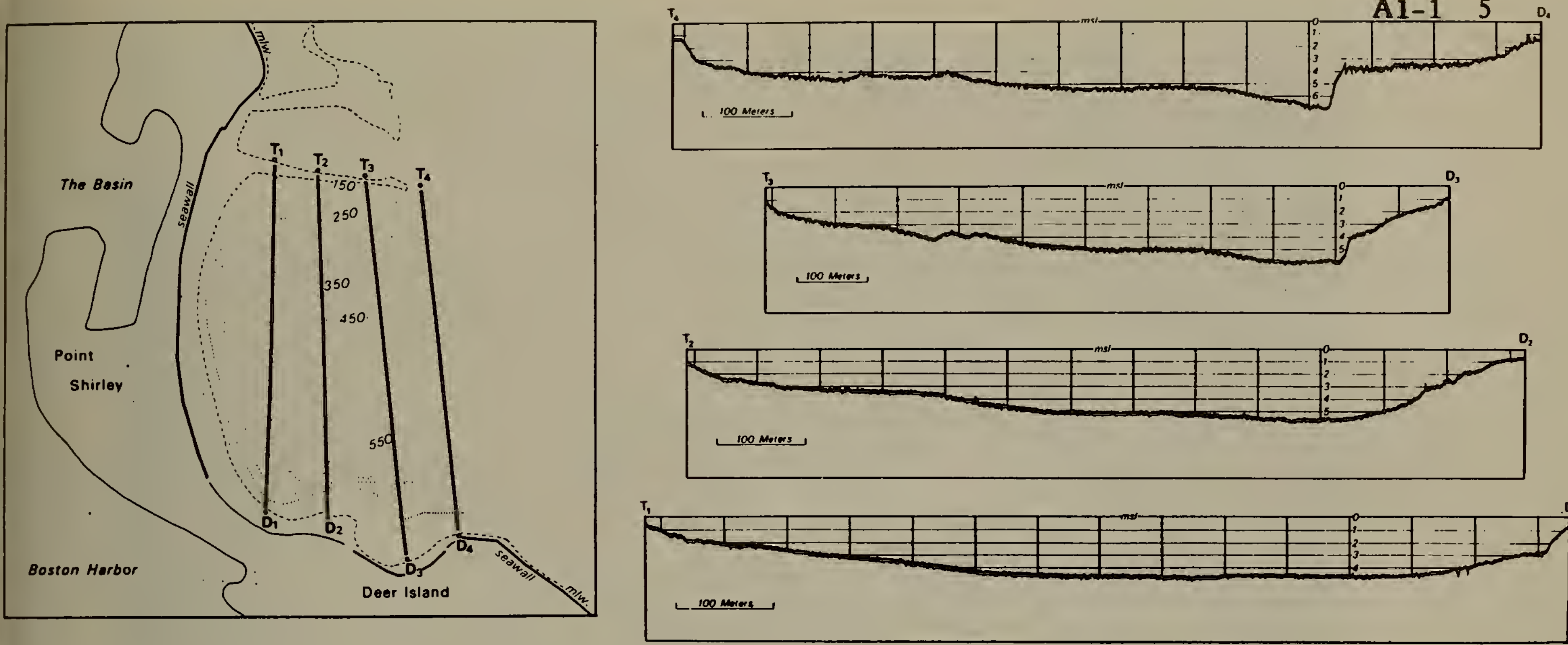


Figure 6. Fathometer profiles off Yirrell Beach.

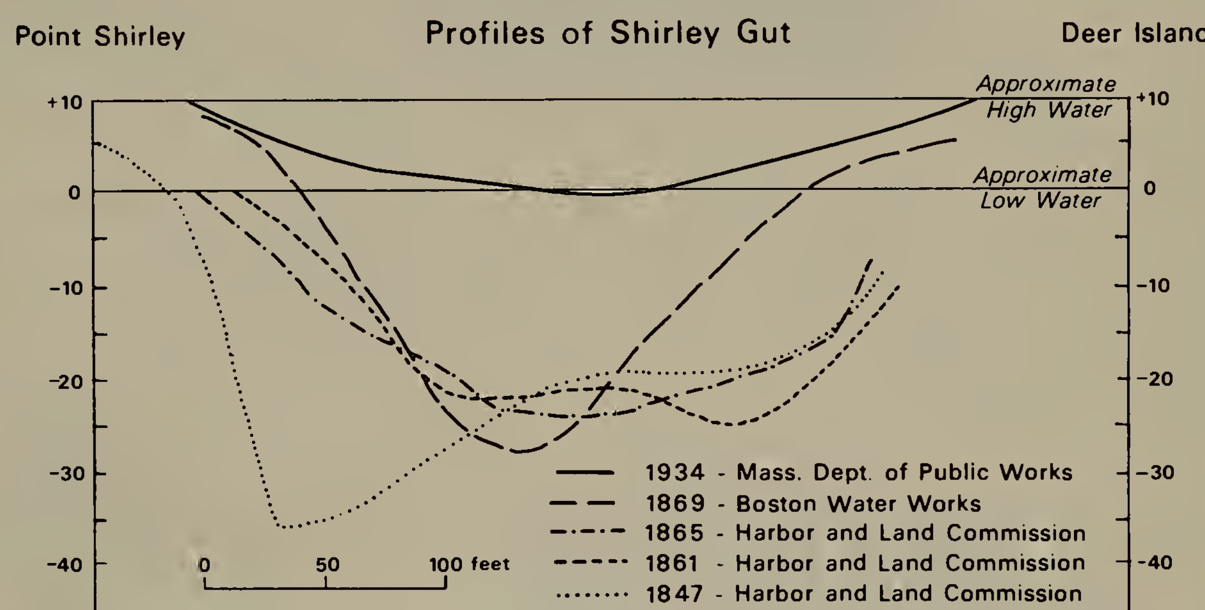


Figure 7. Historical cross sectional profiles of Shirley Gut.

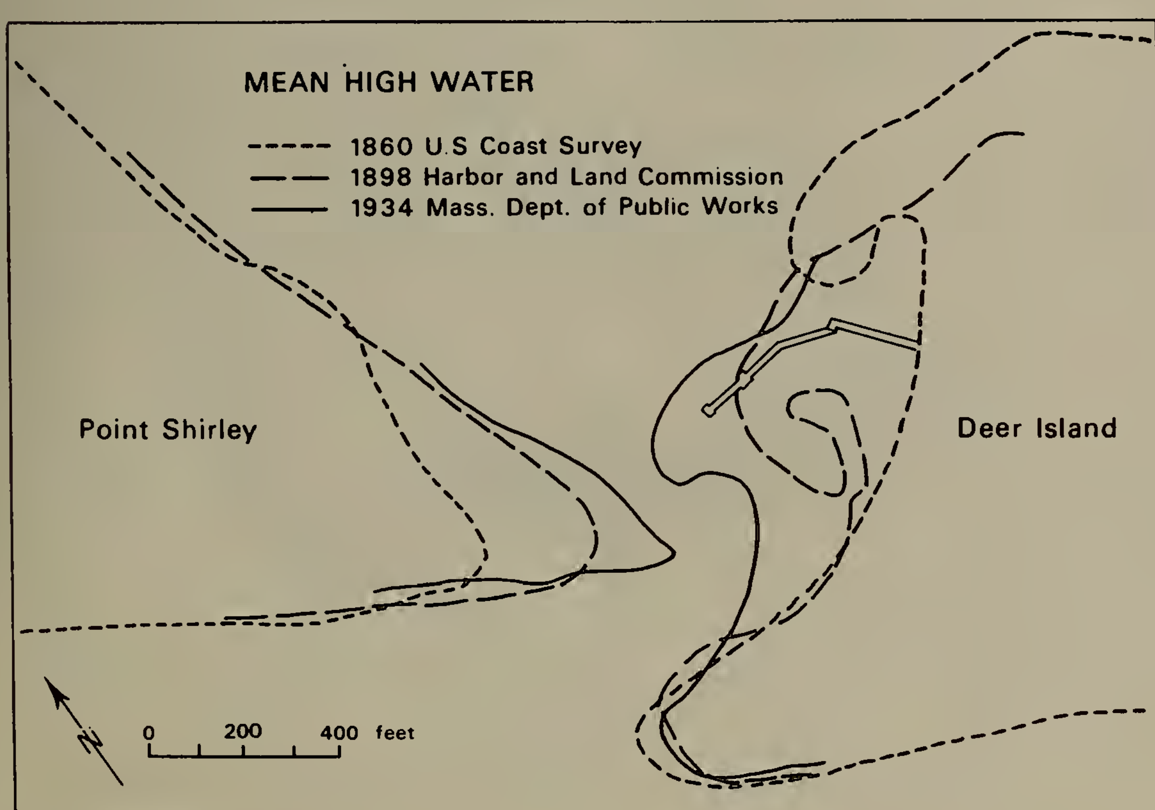


Figure 8. Historical shoreline changes of Shirley Gut.

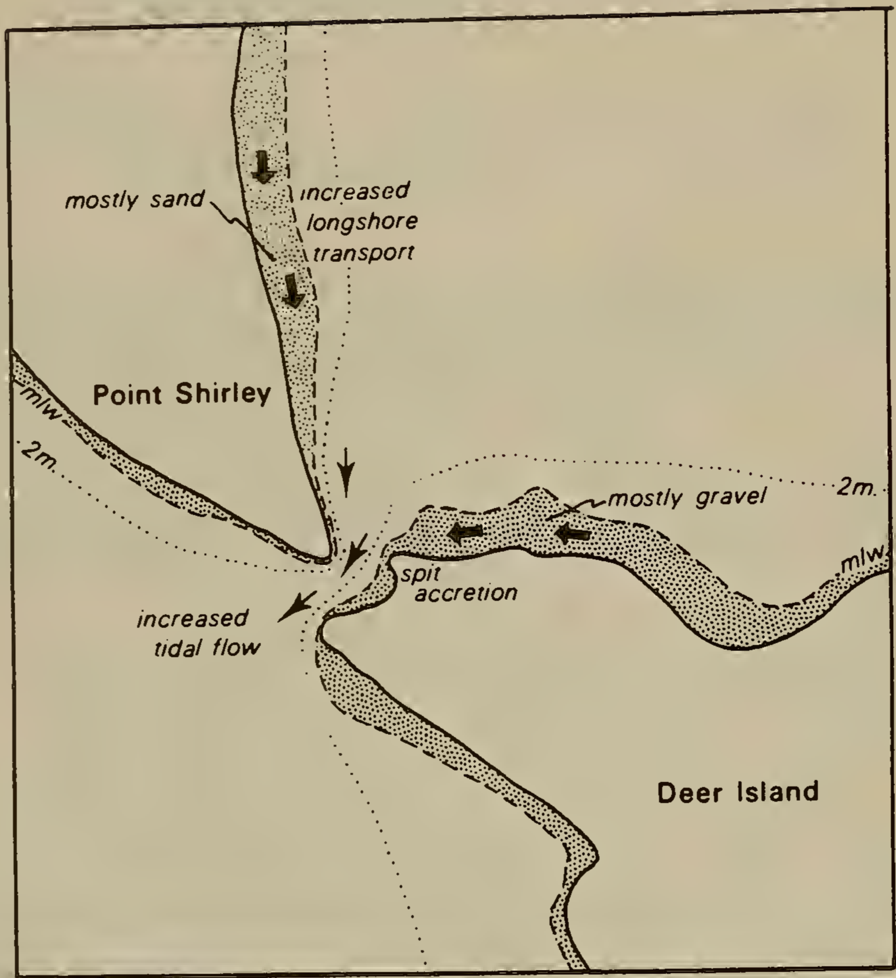


Figure 9. Storm-generated sediment transport patterns and processes at previously opened Shirley Gut.

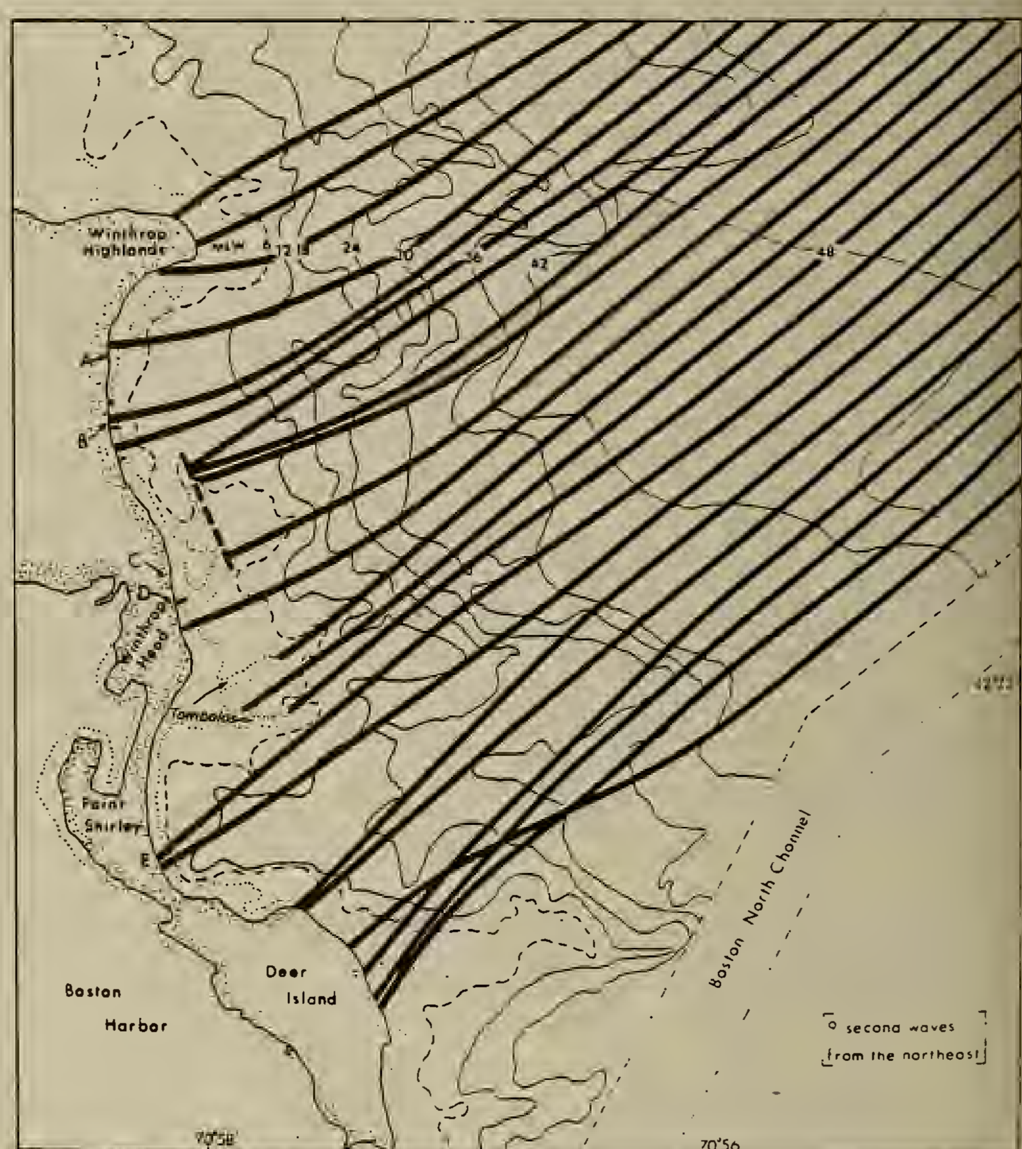


Figure 10. Storm wave refraction diagram for the Winthrop shoreline using 9 sec. waves from the Northeast.

Figure 11. Oblique aerial photograph of sourthern Point Shirley region.
Location A - gravel washover area
Location B - intertidal gravel platform

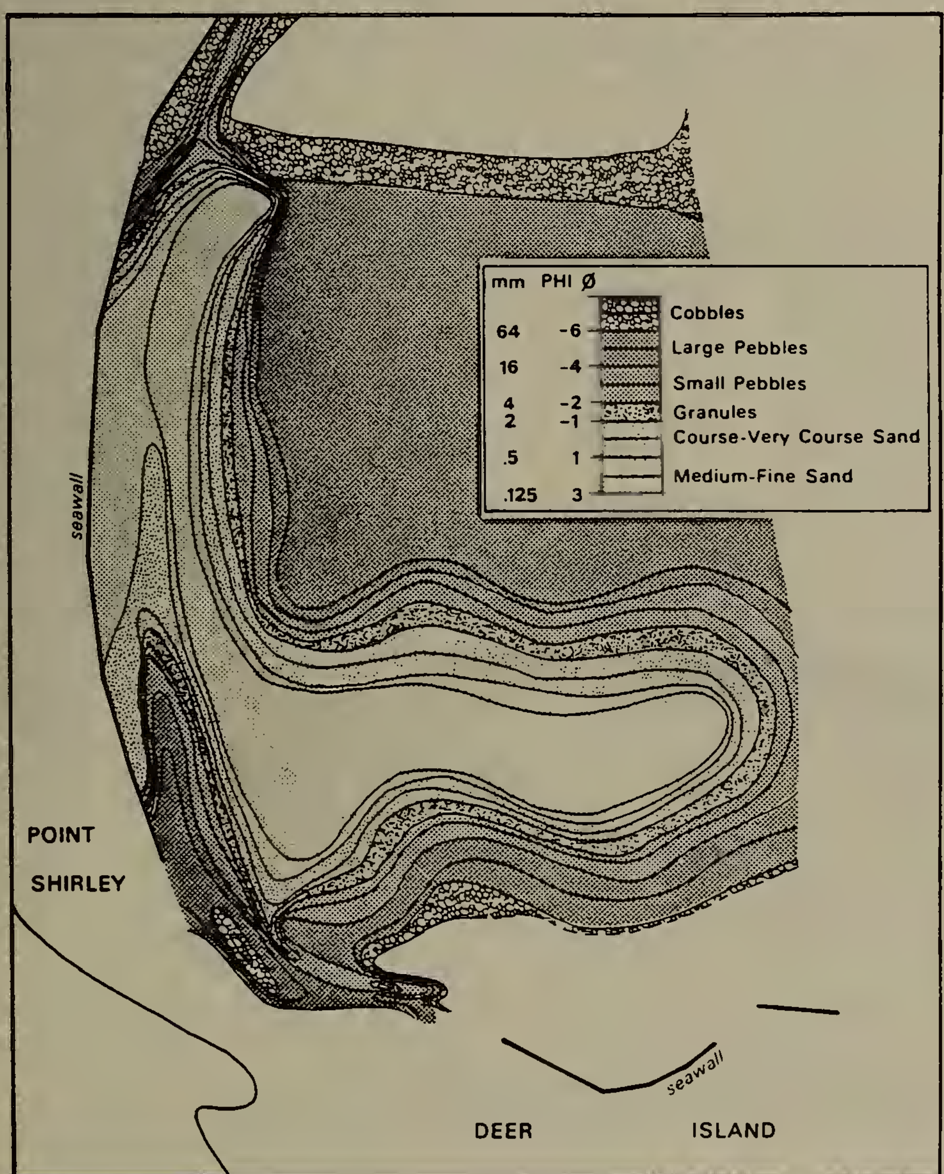


Figure 12. Grain size distribution map of Yirrell Beach and the offshore region. The san offshore of Point Shirley was likely deposited by the ebb tidal currents associated with the previously active Shirley Gut.

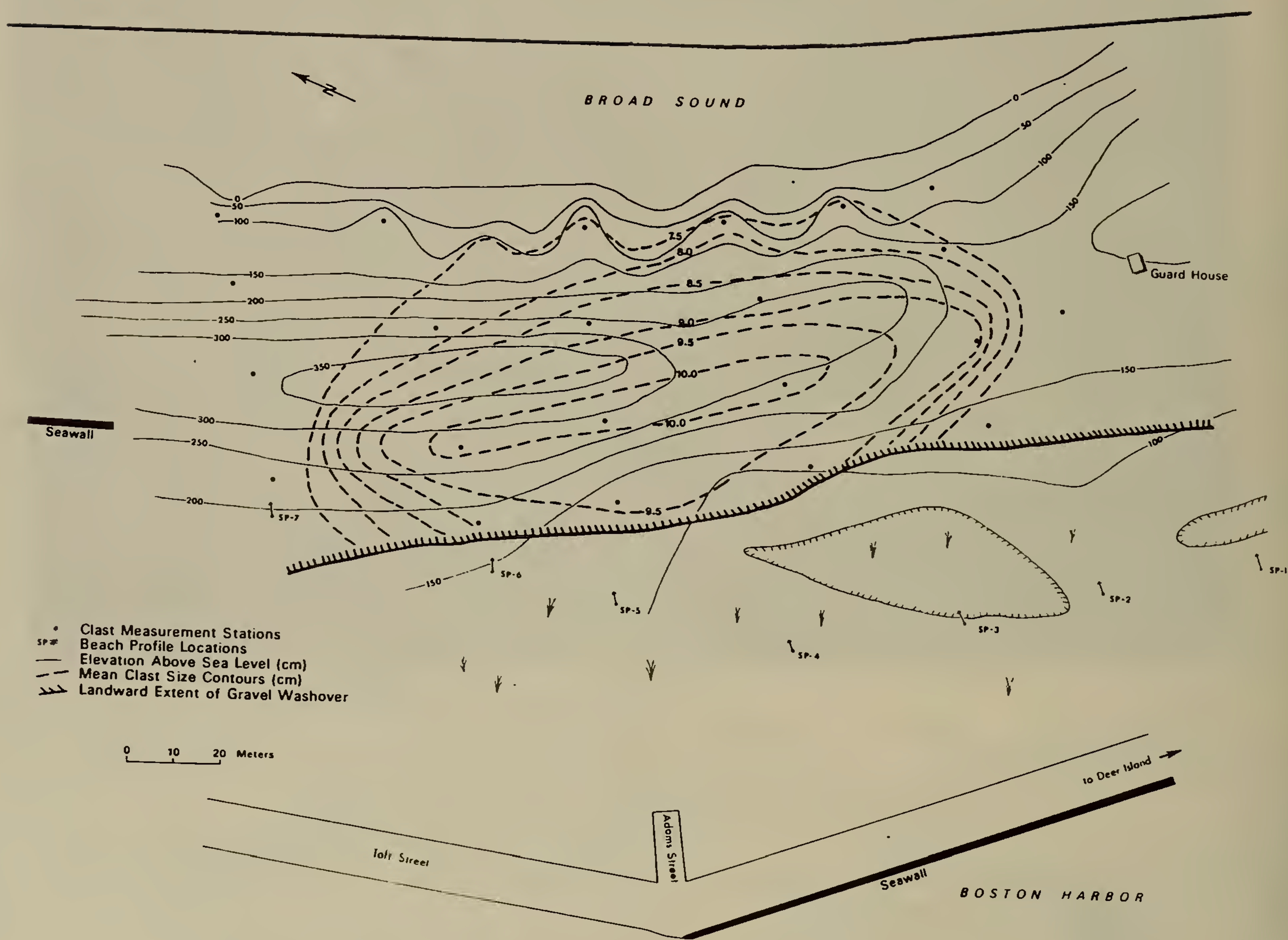


Figure 13. Topographic map and grain size distribution of gravel washover. Note that clast size increases in a landward direction.

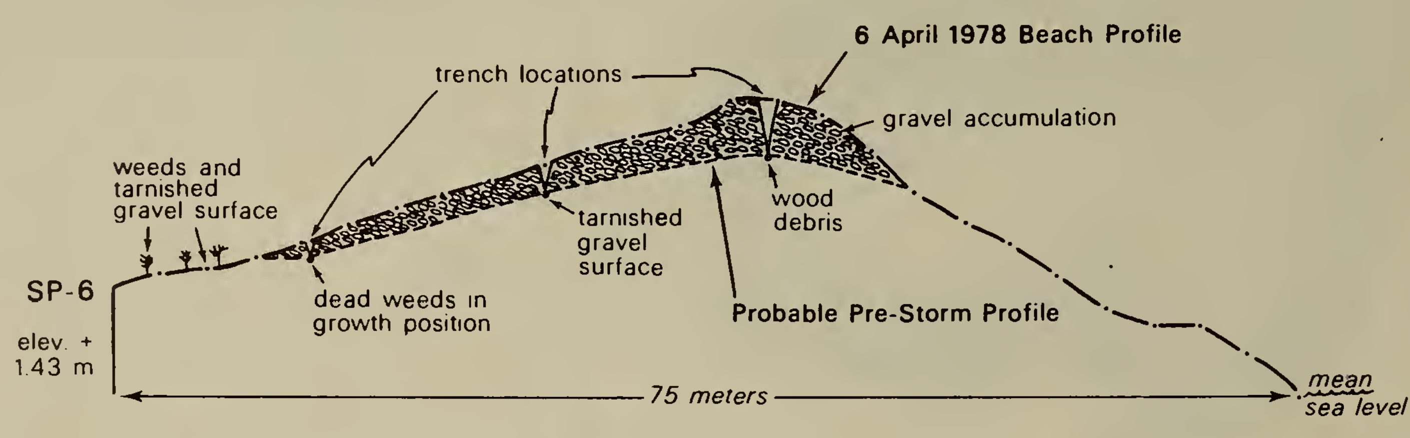


Figure 14. Trench through gravel washover.

The gravel was well imbricated. Long axis clast measurements at 22 stations showed a range in mean clast size of 3.2 to 10.2cm. Gravel shapes consisted mostly of disks and blades, with a few rods, but almost no spheres. This distribution is predicted by Bluck (1967) and also reported for a nearby beach by Brenninkmeyer (1976). Generally, the size of gravel clasts increased in landward direction (Fig. 13). This supprising trend suggests that during intense storm conditions when wave energy is sufficient to move all size fractions on the beach, sediment transport, to a degree, is more a function of clast cross sectional area than weight or fall velocity.

YIRRELL BEACH (Stop #2)

Yirrell Beach is part of a low narrow barrier that connects Winthrop Head to Point Shirley. Prior to the building of numerous summer cottages in the area, Yirrell Beach was backed by a vegetated dune system (Fig. 15). With the development of this region came the need for protection from winter storm damage (Fig. 16). In the 1950's a seawall was constructed along the entire length of the beach. The seawall is normally 1.0 to 1.5m above the level of the sand.

During the Blizzard of 1978 25,000m^3 of coarse sand was transported over the seawall, inundating houses and filling streets to a depth of a meter or more (Fig. 17). U.S. Army bulldozers and front-end loaders were brought in to remove the sand. The sand was placed in front of the seawall and a 600m long artificial dune ridge was constructed (Fig. 18). The source of the sand appears to be a cannibalization of the beach face sediments. A longshore source is unlikely, in that the entire shoreline experienced similar changes. An offshore source is also improbable. As illustrated in Figure 12 the beach sands extend only a short distance seaward of the depositional region.

Although no survey data exist to verify this explanation, beach profiles monitored during a much less severe northeast storm (25 January 1979) suggest a similar trend (Fig. 19). The profiles, which were taken before and immediately after the storm, showed that while the beach face retreated 1 to 6m, the upper berm accreted 10 to 60cm. Unlike sandy beaches that are backed by a foredune ridge and which develop a flat to concave upward profile during storms (Hayes and Boothroyd, 1969), the post storm profile at Yirrell Beach was consistently steeper than the pre-storm profile (Fig. 19). These changes suggest that during storms the beach face is eroded and most of the sediment is moved offshore. However, during the same period the upper beach face sands are transported onshore by wave swash and deposited next to the seawall (Fig. 20). If deposition next to the seawall continues for a long duration then sediment and water will be transported over the wall.

WINTHROP HEAD (Stop #3)

Winthrop Head is one of the many drumlins comprising the Boston Harbor shoreline (Fig. 3). It appears to be the remains of a larger drumlin that was partially destroyed by wave action (Kaye, 1967). It is likely that the greatest rate of drumlin recession occurred during storms when wave erosion caused undercutting and slumping of the adjacent scarp (Fig. 21). During the late 1800's there was a

Figure 15. A view of Yirrell Beach and Deer Island from Winthrop Head (from White, 1893).

Figure 16. Ground photograph taken during the 25 January 1979 northeast storm. Waves are eroding the beach face and depositing some of the sediment next to the seawall.

Figure 17. February Blizzard of 1978 caused $25000 m^3$ of sand to be transported over the seawall along Yirrell Beach.

Figure 18. An artificial dune ridge was constructed from the sand removed from behind the seawall along Yirrell Beach after the February Blizzard.

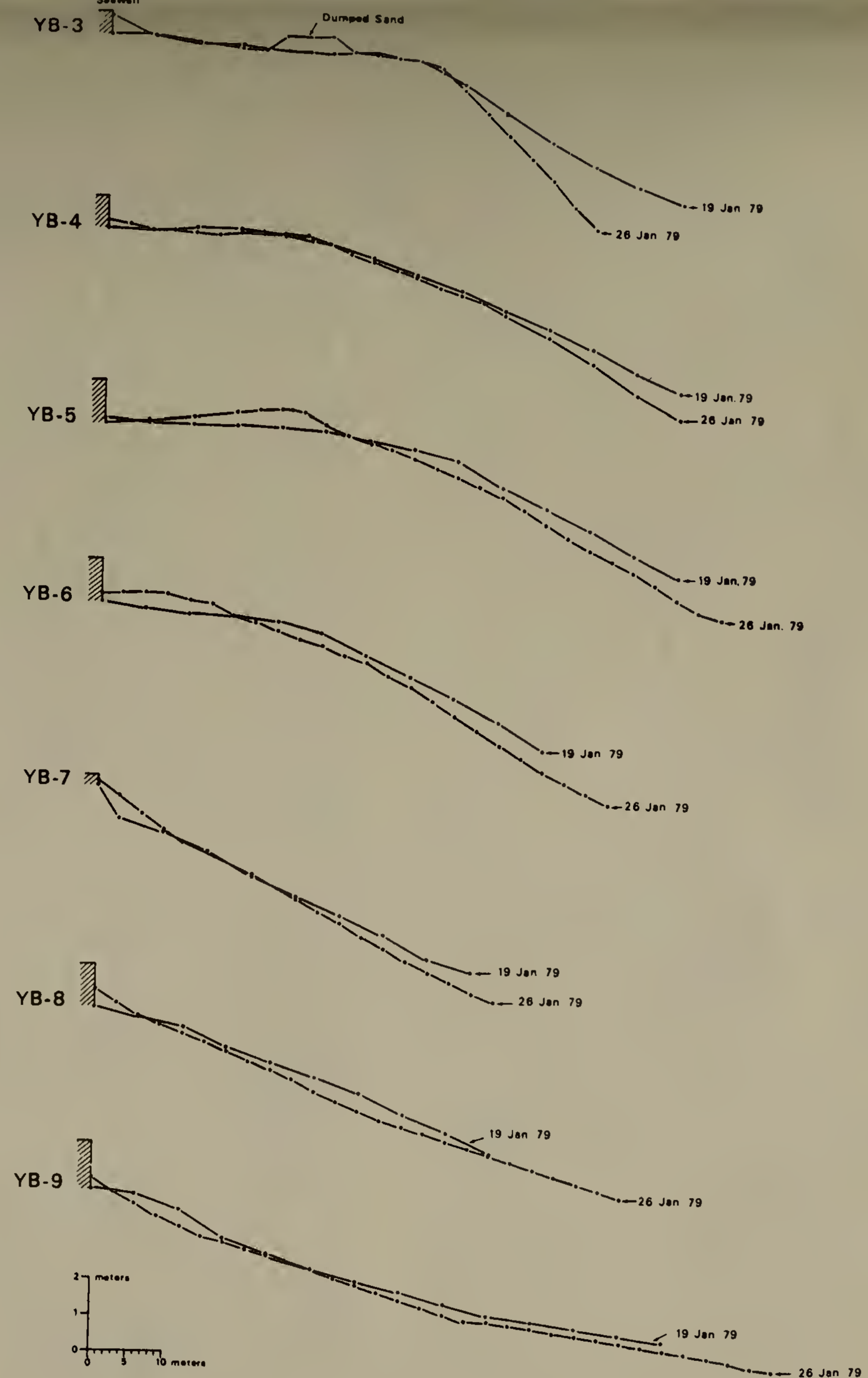


Figure 19. Beach profiles taken along Yirrell Beach before and after a northeast storm. Note the erosion of the beach face and deposition next to the seawall.

Figure 20. Sketch of beach processes active during a storm along Yirrell Beach (Bill Thoen).

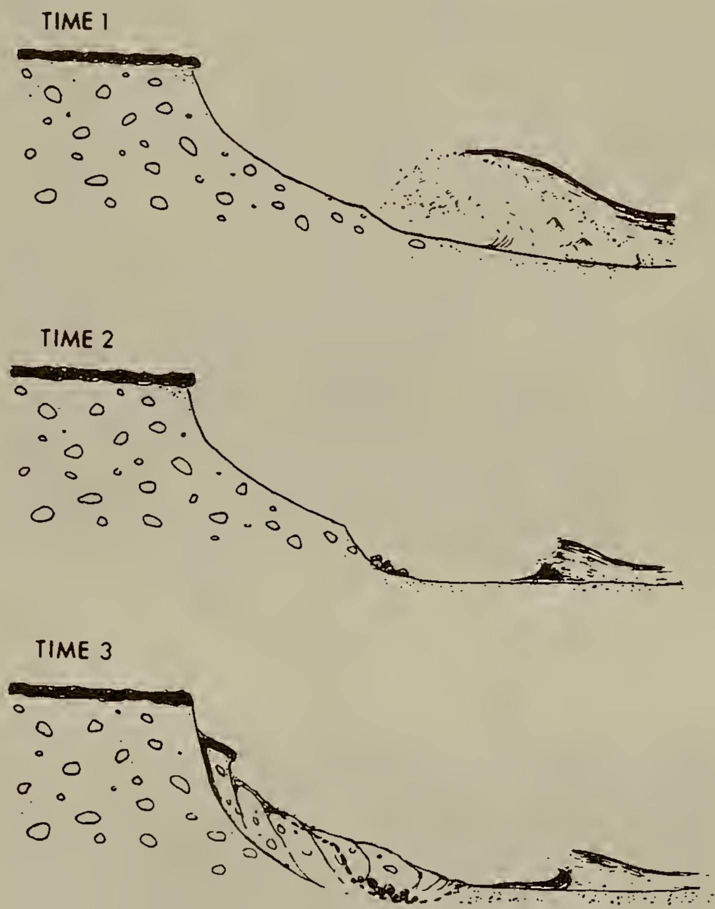


Figure 21. Wave erosion of a drumlin (sketch by Bill Thoen).

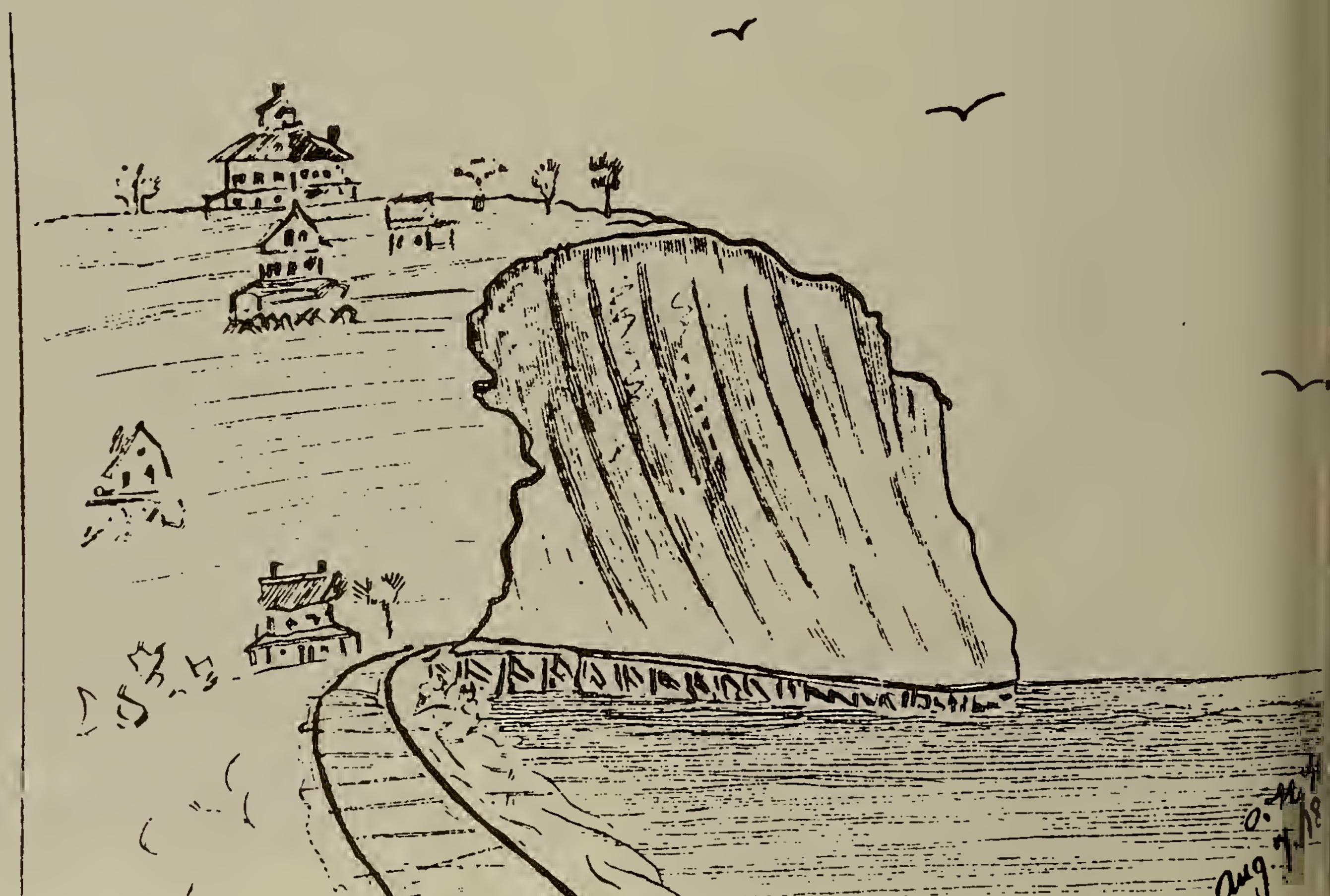


Figure 22. Sketch of railroad trestle in front of Winthrop Head, 1883.

railroad trestle in front of the drumlin (Fig. 22), however, it was demolished during a northeast storm in 1885. In 1927 a 3m high seawall was constructed to prevent further erosion (Fig. 23). However, these attempts have not been altogether successful.

The drumlin is the highest point in the town (31m) and thus is the site of a large standpipe. When the standpipe was built in 1909, it was located about 26m from the edge of the scarp. During the past 75 years the scarp has retreated more than 9m. At the present rate, if no measures are taken to protect the slope, the standpipe will be at the edge of the scarp in the year 2117. Measurements taken over the past four years indicate that this erosion rate is much too conserative. Also, it should be emphasized that as the scarp moves closer to the standpipe, the overburden of 5000 tons can be expected to cause a failure of the slope much sooner than orginally predicted.

Seaward of Winthrop Head is a double tombolo system that extends approximately 500m offshore (Fig. 24). The tombolos consist primarily of cobble-sized gravel which is believed to have been derived from an offshore eroded drumlin. The southern tombolo is present in the oldest U.S. Coast and Geodetic Survey charts dating to 1857. However, the northern tombolo was first documented in a 1945 vertical aerial photograph. A map of the morphological changes of the bars between 1945 and 1978 is shown in Figure 25. Note that during this 33 year period of time the ends of the tombolos were progressively flattened and moved onshore. Today the bars are joined at seaward ends and the northern tombolo has a spur that extends far to the northwest.

SOUTHERN WINTHROP BEACH (Stop #4)

The southern end of Winthrop Beach is comprised of sand and gravel and is characterized by a narrow or nonexistent high tide beach (Fig. 2). The region is backed by seawalls of various constructions (Fig. 26) and contains a number of groins. It is interesting to observe the riprap on both sides of the southern most groin. The 1 to 2 ton stone on the southern side of the groin has been there for about 30 years and is moderately rounded. The riprap on the northern side was placed there in 1980 and still retains many highly angular edges.

Riprap was put along the base of the seawall at Winthrop Beach to protect the wall during storms and to prevent wave reflection. Storm waves entrain large amounts of gravel which are propelled against the wall during each breaking wave. The riprap therefore abrades instead of the wall.

When waves break directly on the seawall much of the wave energy is reflected and propagated back offshore to meet the next incoming wave. This results in increased turbulence and offshore sediment transport (Fig. 27) (Herbick and Ko, 1968). Riprap in front of seawalls causes waves to break thereby reducing the reflection process. Many of the Boston area beaches have had seawalls along their shorelines for over 50 years. In these areas the shoreward erosion has been halted but vertical erosion has resulted in little or no high tide beach.

Beach profiles monitored in the southern Winthrop Beach region (Fig. 1, Location WB-1-3) during the winter of 1980 have revealed

Figure 23. Late 1920's photograph of Winthrop Head. Note the seawall that has been constructed of the eroding drumlin.

Figure 24. Oblique aerial photograph of the double tombolo system off Winthrop Head.

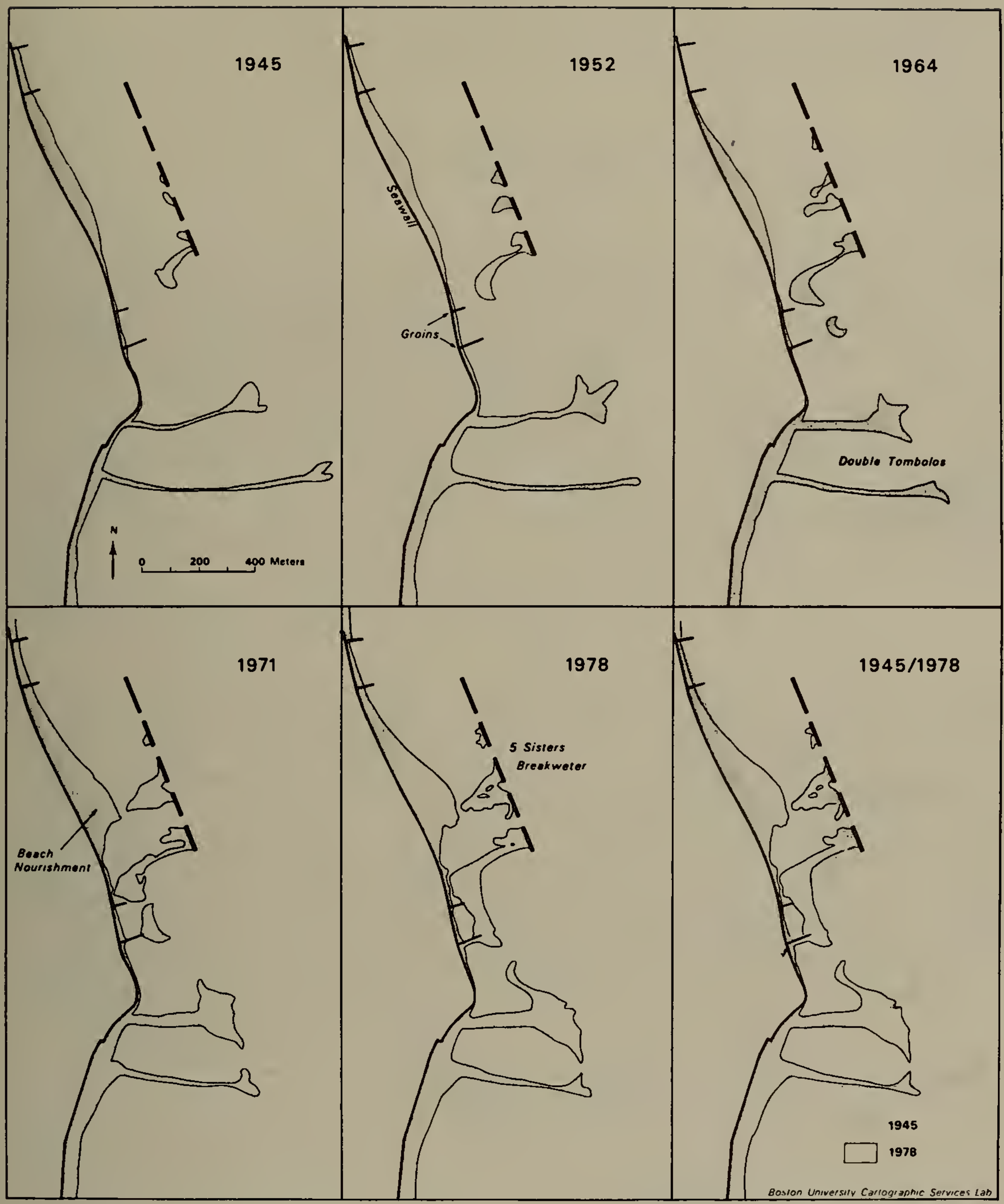


Figure 25. Historical morphological changes of the double tombolo system and gravel bars at the Five Sisters Breakwater.

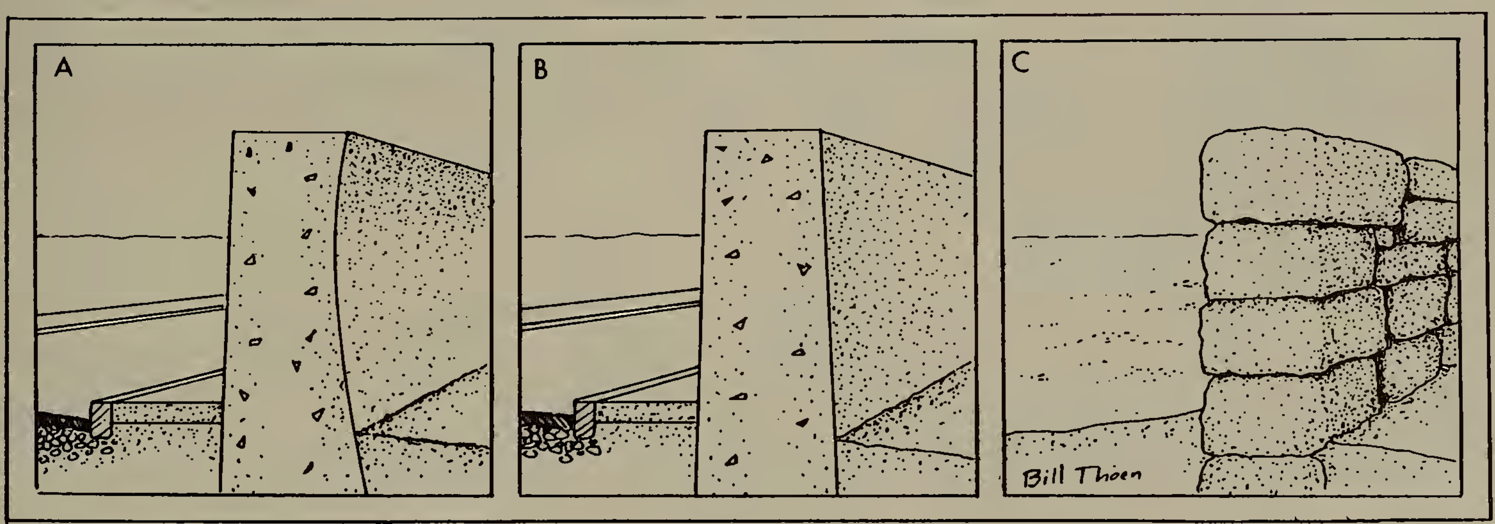


Figure 26. Sketch of various seawall constructions along Winthrop and Yirrell Beaches (by Bill Thoen).

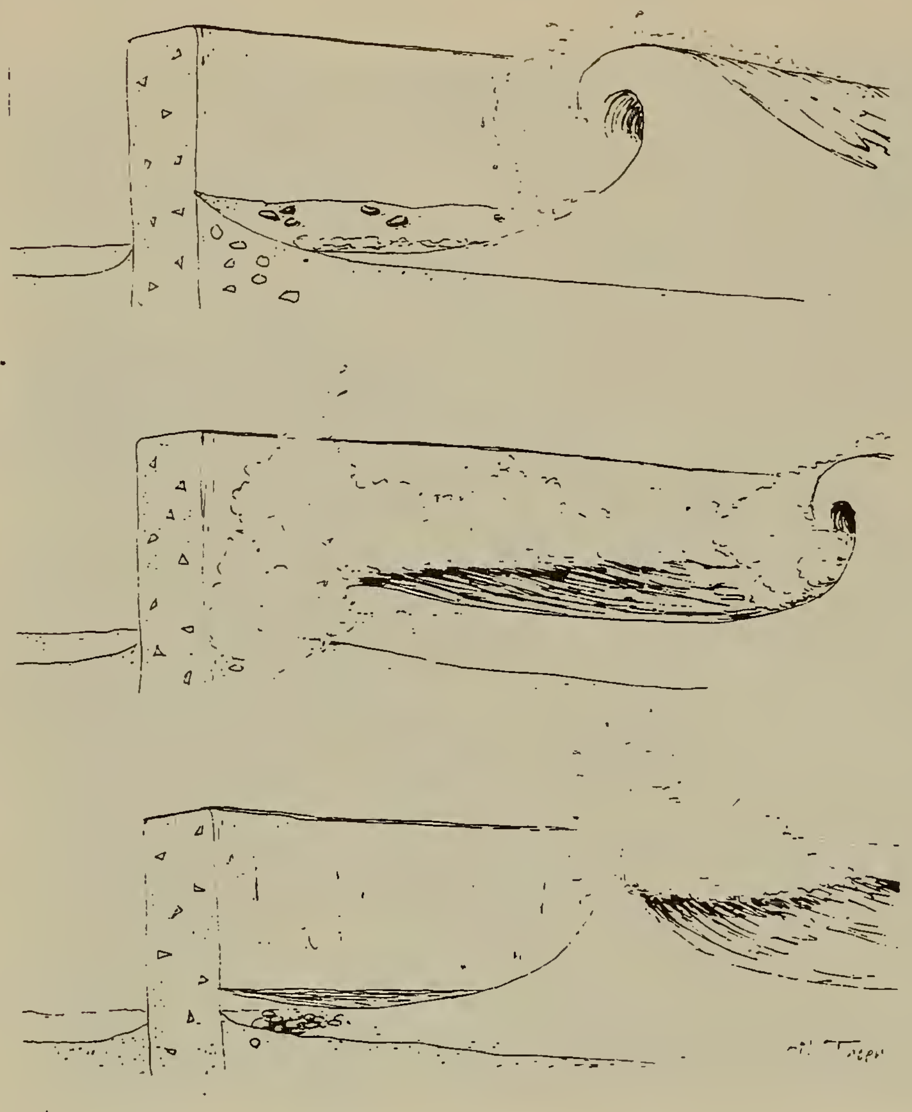


Figure 27. Process of wave reflection results in seaward transport of sand and vertical erosion next to seawalls (sketch by Bill Thoen).

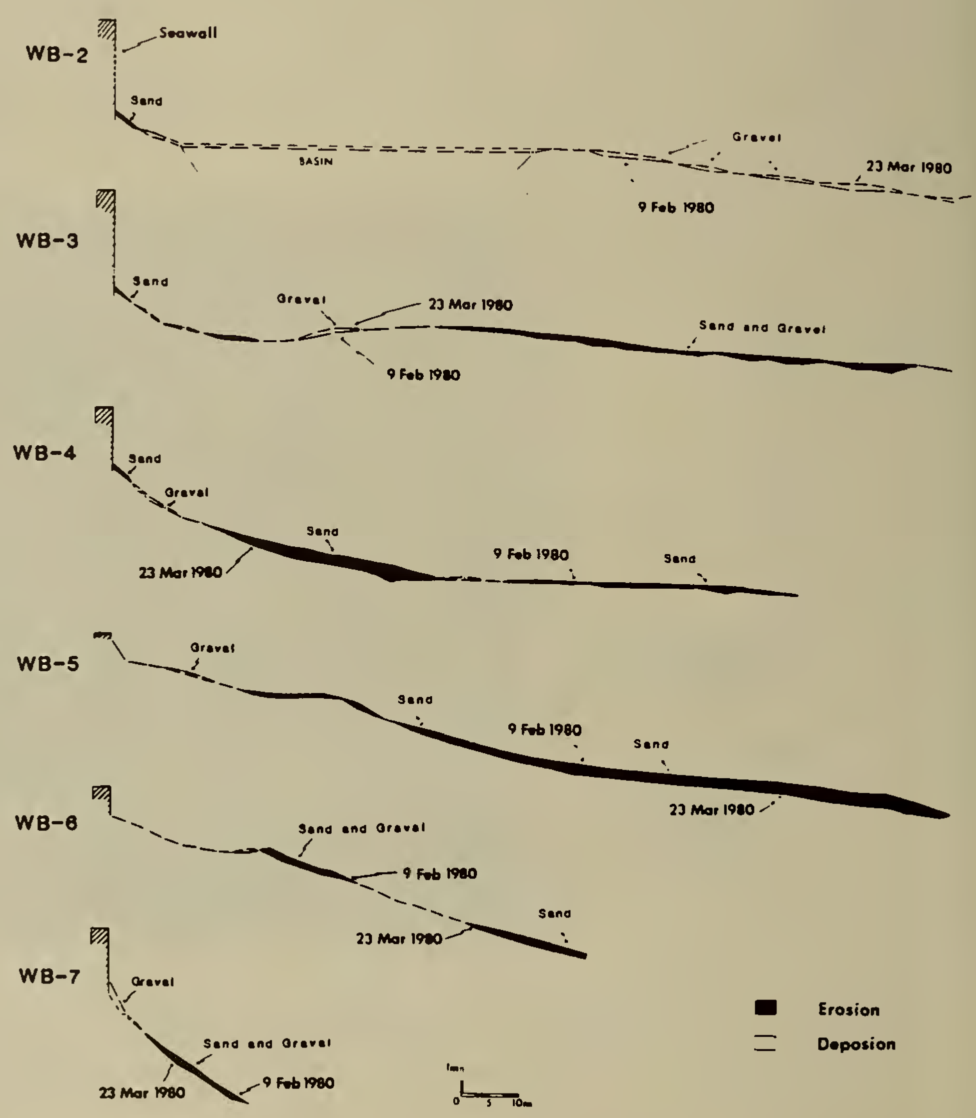


Figure 28. Profile changes along Winthrop Beach due to a northeast storm. Note that sand is eroded while gravel is deposited.

two basic sedimentation trends (Fig. 28). During storm conditions sand is moved offshore while gravel is transported onshore. The only gravel locations that experienced erosion were areas in which wave reflection was an active process.

FIVE SISTERS BREAKWATER (Stop #5)

The Five Sisters Breakwater is located 300m offshore of the middle of Winthrop Beach (Fig. 2). It extends along a 700m stretch of shoreline and is built of piled granite blocks rising to a height of 3-4m above mean high water. Prior to its construction the shoreline behind the breakwater was eroding at a rate of $1250m^3$/yr. After completion of the project the beach accreted at a rate of $3000m^3$/yr. The deposition of sand in this area is attributed to wave refraction causing the longshore transport of sand toward the sheltered area behind the structures. This location has also been the site of sand nouishment.

Seaward of the breakwater is an eroded drumlin that rises to within 1.0m of mean low water. The gravel component of the drumlin has been transported onshore and deposited between sections of the breakwater. As illustrated in Figure 25 there have been substantial gravel bars that have formed behind the structures since 1945. Wave surge measurements made in the openings of the breakwater during low wave energy conditions ($H < 1.0m$) recorded velocities up to 30cm/sec (Fig. 29) (Sullivan, 1982). During storms, when waves are much larger, surge velocities would be much greater and more than adequate to move the gravel onshore.

NORTH WINTHROP BEACH (Stop #6)

The northern end of Winthrop Beach is highly structured with three groins and a massive seawall (Fig. 30). Riprap was placed two-thirds of the way up the height of the seawall in 1980. This amount of protection is neccessary due to the direct exposure of this region to wave energy. A beach is absent in this area and the nearshore slopes steeply to >4.0m within 300m of the shoreline. Under normal conditions, waves break on the seawall from mid to high tide, but during storms waves assault the wall continuously.

During the February Blizzard of 1978 a 10m section of the seawall was dismantled, leading to an undermining and collapse of the adjacent sidewalk and roadway (Fig. 31). The wall that failed was built of large stacked granite blocks that originally, had been held together with cemented (Fig. 26). At the time of the storm much of the mortar had been remove through abrasion, frost wedging and wear. This allowed the storm waves to more easily pluck granite blocks from the wall.

In other areas the seawall is constructed of reinforced cement and has a curved face (Figs. 26 and 32). During intense storms, prior to the placement of the riprap, storm waves that broke higher up the wall were only partially reflected. Most the water within one of the breaking waves was propelled upward to heights as great as 15m above the top of the wall (Fig. 33).The occurrence of these water fountains was dependent on an elevated sea level, and they increased in height with increasing wave height. The vertical uprush of water entrained sand and gravel at the base of the seawall and

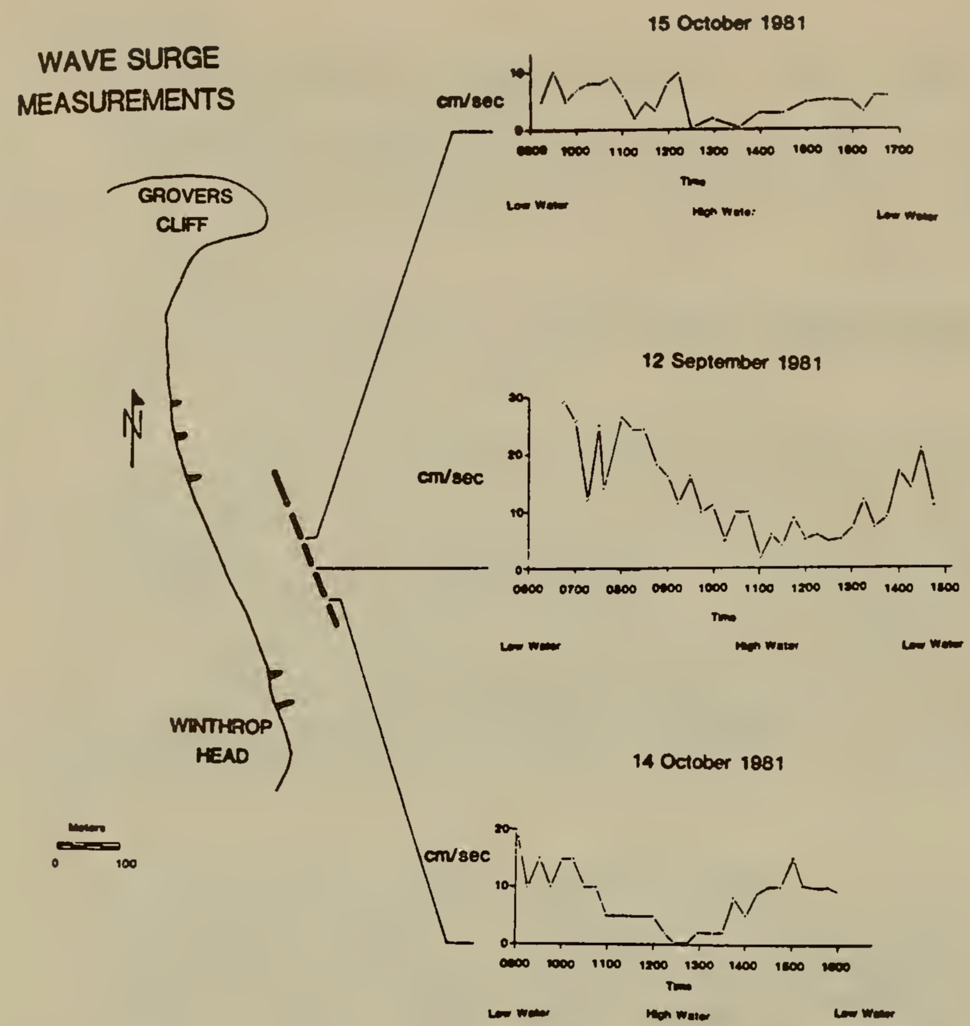


Figure 29. Wave surge current velocities measure between the sections of the Five Sisters Breakwater (from Sullivan, 1981).

Figure 30. Oblique aerial photograph of the northern portion of Winthrop Beach.

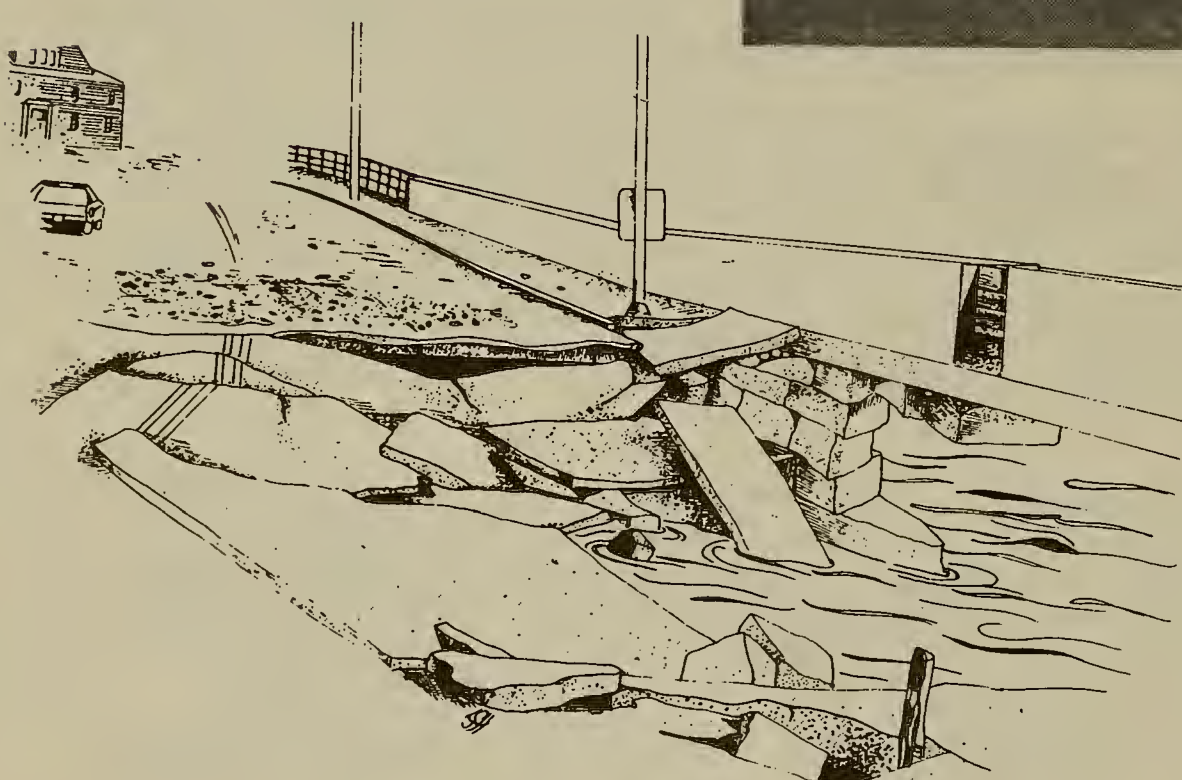


Figure 31. Sketch of the collapse of the sidewalk and roadway that occurred during the February Bizzard of 1978 at Northern Winthrop Beach (by Lindley Hanson).

propelled it skyward. Once above the top of the seawall the strong onshore winds, that accompany northeast storms, blew the water and sediment mixture onto the the adjacent street (Fig. 33). During the Blizzard of 1978 gravel projectiles that were transported over the seawall by this mechanism filled streets and ripped apart nearby houses.

To retard the water fountains and the ensuing gravel projectiles, riprap was placed against the wall in 1980 (Fig. 34). Prior to this time, deposition next to the seawall was prevented due to wave reflection processes. With reduced wave energy the onshore movement of gravel was allowed to accumulate around the riprap. The gravel slope that was formed by this process provided a ramp for water and gravel to be moved over the seawall during even moderate storm wave conditions (Figs. 35 and 36). Beach profiles shown in Figure 37 illustrate the changes to the beach. Thus, in this case, the riprap while protecting the seawall exacerbated the problem of transport over the wall.

CONCLUSIONS

A summary of the sedimentation processes along the Winthrop coast is illustrated in Figure 38. A consistent trend of storm generated sediment transport has been documented for this region. Gravel is moved onshore while sand is transported offshore. This pattern is corroborated by the gravel washover that occurred at Point Shirley, the historical flattening of the double tombolo system, the build up of gravel between sections of the breakwater and the accumulation of gravel around the riprap. It also has been documented with beach profile data that during storms sand is eroded from Winthrop and Yirrell Beaches. The large volume of sand that was transported over the seawall at Yirrell Beach during the February Blizzard of 1978 was likely attributable to beach face erosion and wave swash processes.

The riprapping of the seawall along northern Winthrop Beach that was done to prevent water fountains and gravel projectiles has had mixed results. Although the riprap has protected the wall from abrasion, a gravel ramp has been formed in the absence of wave reflection processes. This has led to more frequent occurrences of water and gravel being transported over the seawall.

ACKNOWLEDGEMENTS

The research along the Winthrop coast was funded by the Town of Winthrop and Massachusetts Coastal Zone Management. The author would like to acknowledge the individual studies and field assistance of the following Boston University graduate students: David Sullivan, Andrew Magee, Larry Oates, Doug Levin and Andrew Bakinowski. Dr. Denis D'Amore is thanked for his detailed investigation of the Winthrop Head drumlin. The sketches in this paper are the art work of Bill Thoen and Lindley Hanson. The figures were done by Eliza McClennan of the Boston University Cartographic Services.

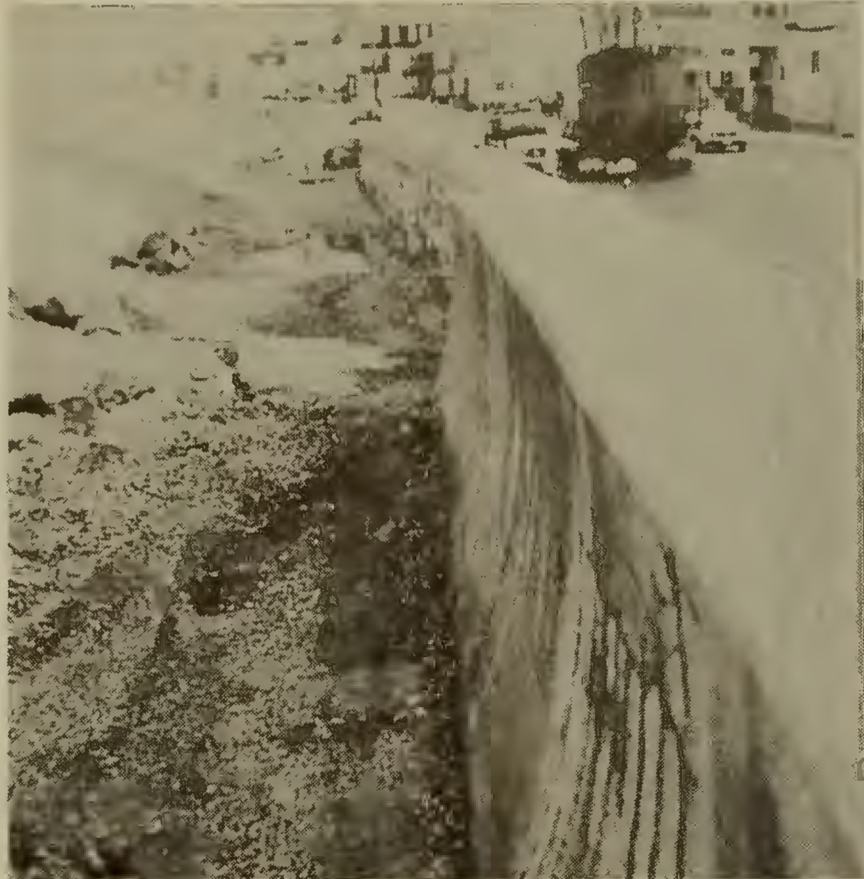


Figure 32. Cured-face seawall.

Figure 33. Water fountains along northern Winthrop Beach.

Figure 34. Riprap along northern Winthrop Beach. Photograph taken right after completion of project.

Figure 35. Gravel that had accumulated around riprap.

Figure 36. Photograph of water and gravel being transported over the seawall after the seawall had been riprapped.

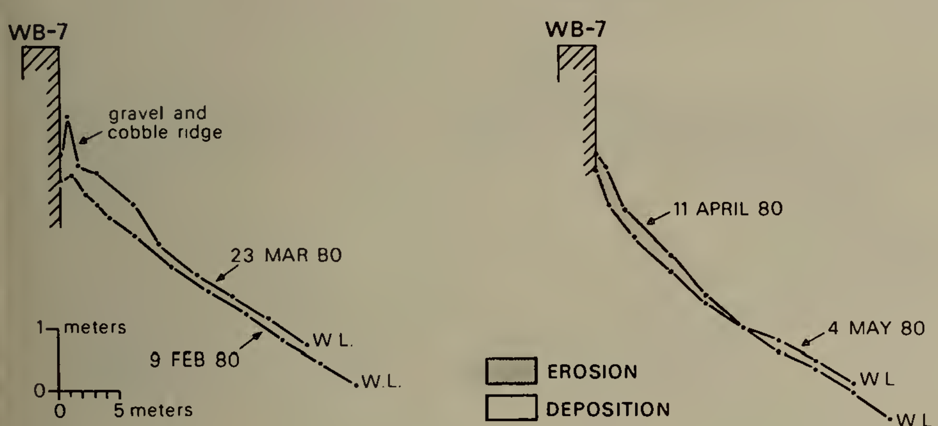
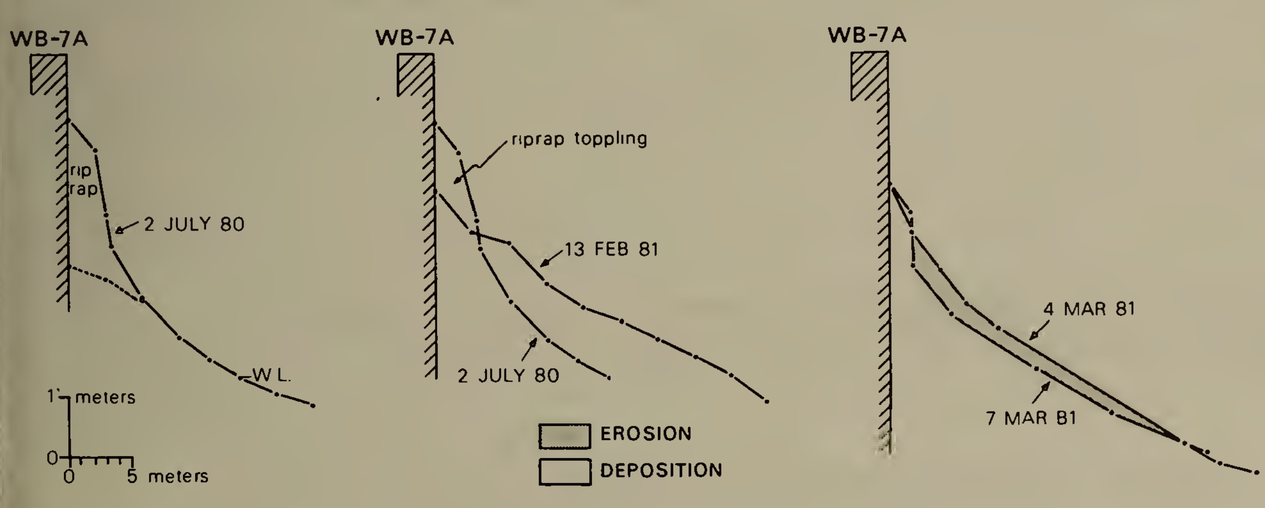


Figure 37. Profile changes to the beach. Note deposition that occurred after the initial riprap was placed along the seawall and the subsequent storm induced erosion. Some of the eroded gravel transported over the seawall.



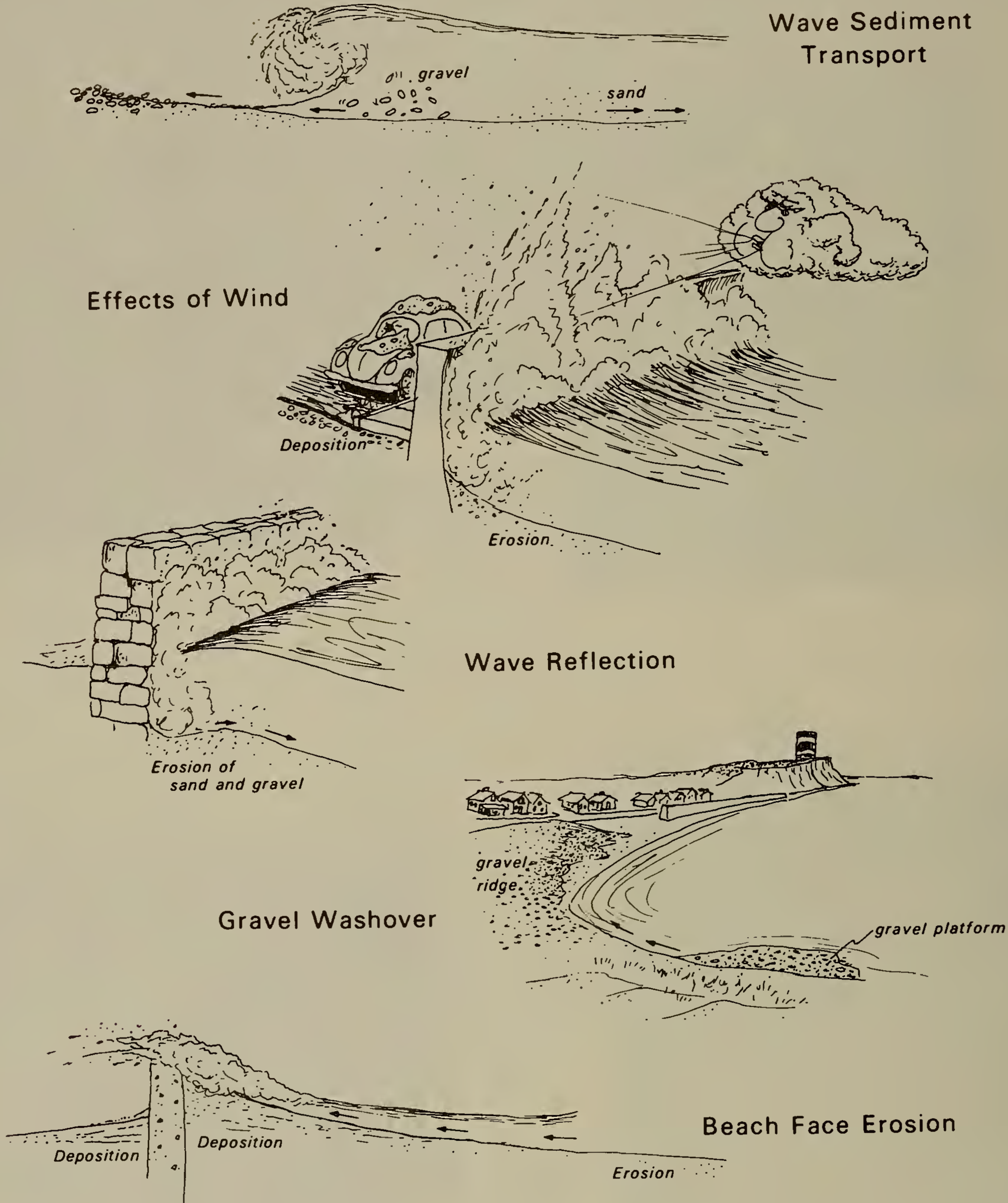


Figure 38. Summary of physical processes along Winthrop and Yirrell Beaches.

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BEACH LOG

The field trip will begin at the gate to the Deer Island Prison. Please don't check in. There are parking lots on the right and left. Please use the left parking lot (on the ocean side).

Kilometers

0.0 STOP #1 Shirley Gut.
Inlet filling, Gravel washover

0.7 STOP #2 Yirrell Beach
Storm processes, Beach management

1.5 STOP #3 Winthrop Head
Drumlin erosion, Tombolos

1.9 STOP #4 Southern Winthrop Beach
Coastal structures, gravel transport

2.2 STOP #5 Five Sisters Breakwater
Gravel bars, Wave surge processes

3.0 STOP #6 Northern Winthrop Beach
Riprap, Transport over the seawall

Ride by bus back to the Deer Island parking lot. Proceed to South Boston to take the ferry to Thompson Island.

GRAVEL SPIT PROCESSES, THOMPSON ISLAND, BOSTON HARBOR, MASSACHUSETTS

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Boston, Massachusetts 02115

Introduction

Thompson Island is one of nearly 30 islands in Boston Harobr created by submergence of Pleistocene drumlinoid topography (Figure 1). Modern wave processes in this low energy setting have reworked the eroding unsorted gravel to create a variety of accumulative landforms, including longshore spits, cuspate spits, and tombolos. Thompson Island has two cuspate spits and one longshore spit.

The longshore drift directions on the island are controlled by wave refraction patterns around the island. Oncoming waves refract around the island, so a drift convergence can form at the leeward side resulting in the formation of cuspate spits.

Boston Harbor mouth opens into Massachusetts Bay with a direct northeast exposure. However, Thompson Island is sheltered from the harbor mouth. Therefore, locally-generated seas can play a role in affecting net drift directions. Along the eastern shore of the island, net drift is toward both the north and south directions, representing influence from both the prevalent southwest and dominant northeast winds.

There is no onshore-offshore cycling of sediments on the beaches. The nearshore zone is composed of sandy silts derived from the fine fraction of eroding Pleistocene bluffs.

South Cuspate Spit

The South Cuspate Spit is one of the few accumulative forms in Boston Harbor with a high percentage of sand. Therefore, the emergence and preservation of the landform results from dune growth above the gravel beach. Figure 2 shows longshore currents converging at the spit in response to a northern wave approach. This figure also demonstrates that the cuspate form represents a reorientation of the shore into two opposing wave approach directions. A dearth of source material to the south (due to blocking by the South Longshore Spit), and abundance of source sediments to the north (due to an eroding, sandy bluff) results in gradual accumulation of the spit northward. This trend is recorded in a succession of preserved dune ridges parallel to the northern shore (Figure 3). There has been no discernable change in the shore position since 1847.

Boston Harbor

FIGURE 1

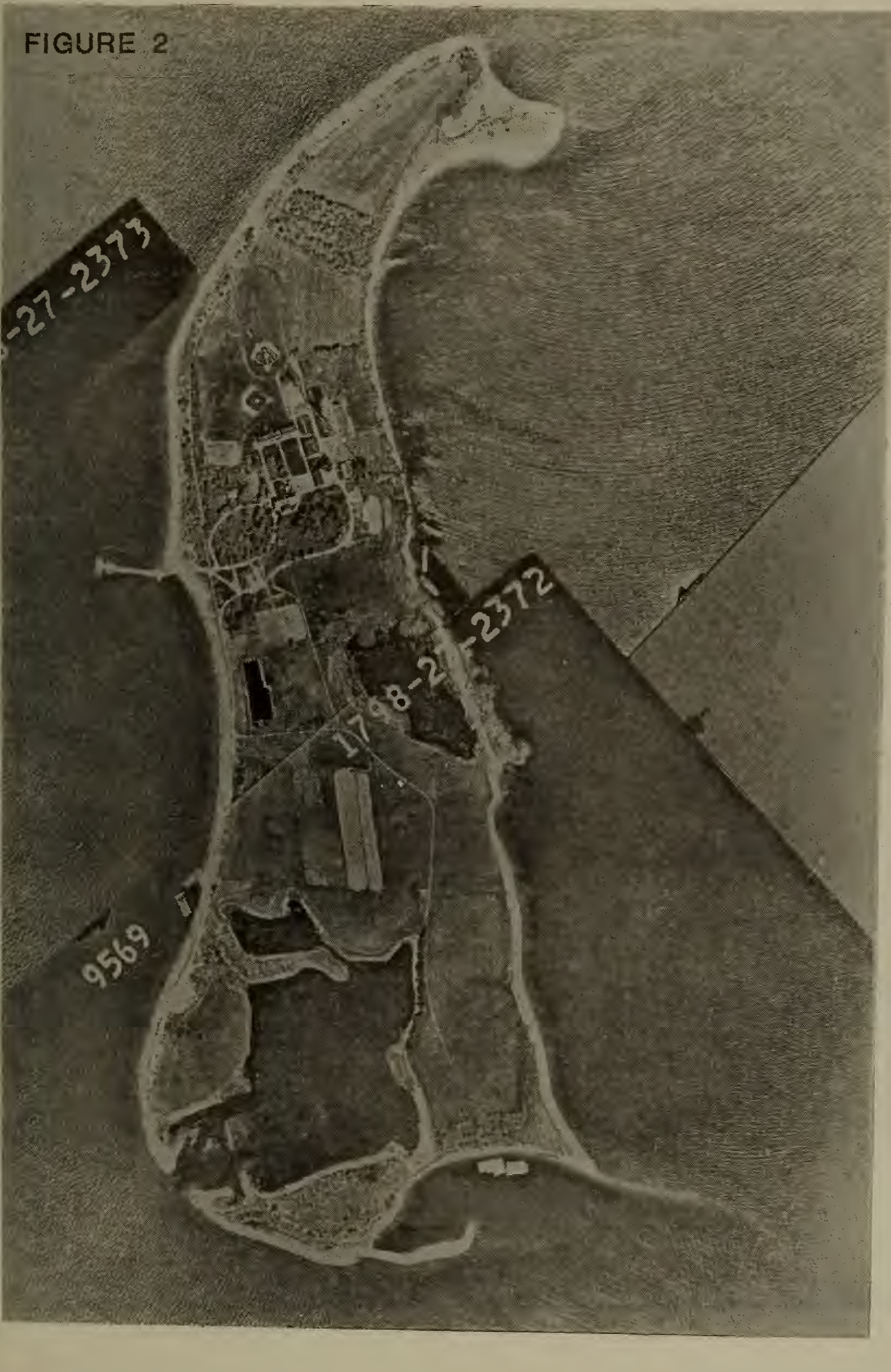
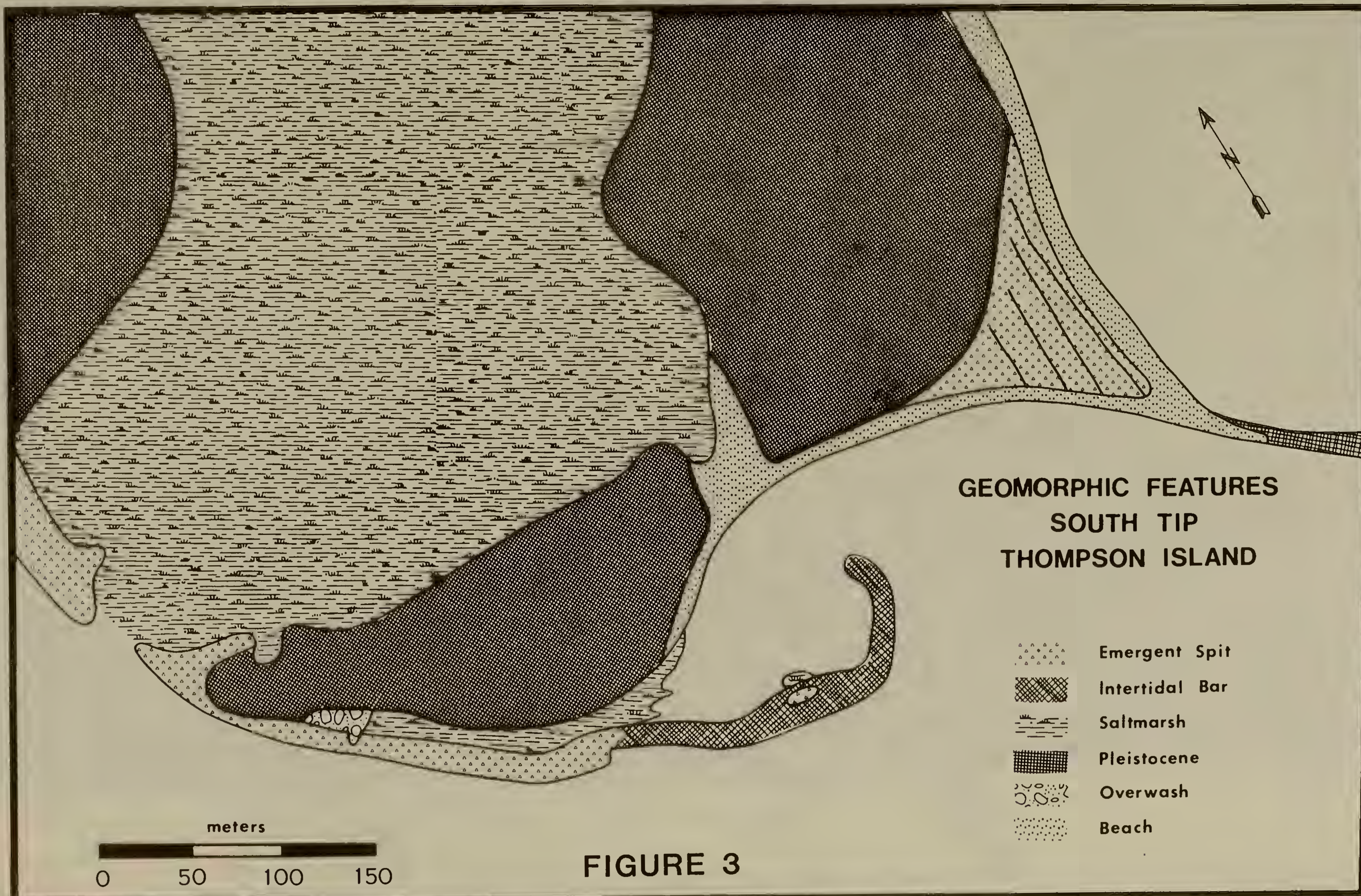


FIGURE 2
-27-2373
2372
9569



GEOMORPHIC FEATURES
SOUTH TIP
THOMPSON ISLAND

FIGURE 3

The spit ends in a bar that extends across a channel to Squantum Head. This bar represents the initial stages of tombolo formation. The bar has not emerged due to scouring by tidal currents. Since the bar has been relatively stable since 1847, it appears to represent an equilibrium between longshore sediment input and tidal scour.

North Cuspate Spit

The gravel comprising the North Cuspate Spit has a low sand content and no dune formation. The spit is greater than 2550 years old, based on Carbon-14 dates of the enclosed salt marsh (Clifford Kaye, USGS, personal communication). The spit has grown seaward on a base of nearshore muds (Figure 4).

The gravel has a high percentage of Cambridge Argillite pebbles, which may underly the glacial sediments in this area. This results in a dominance of flat (disc or blade) shapes. As is typical of gravel beaches, flat shapes are preferentially transported landward, while round (spheroids and rods) shapes are transported seaward. Storm wave activity results in net onshore transport and the formation of flat-pebble accumulative ridges above the high water line. The ridges form the emergent portions of the spit. The accumulative ridges have been deposited successively on the southern face of the spit, at least partially due to the abundance of source material from that direction. Tracings of the ridge crests from aerial photographs have shown that the spit was initially more parallel with the original shoreline of the submerged glacial materials (Figure 5). Successive storm ridge accumulation has reoriented the shore to a position nearly parallel to oncoming southerly waves.

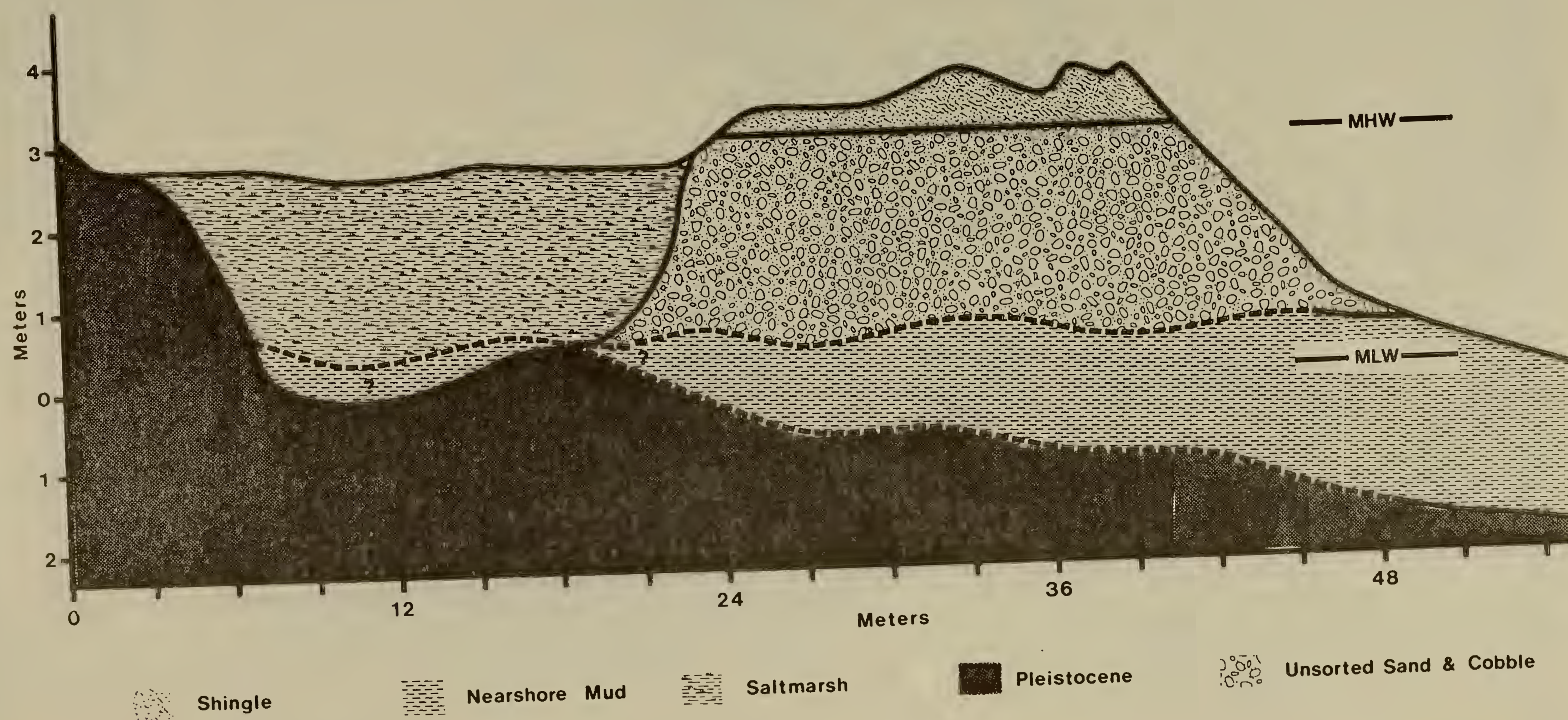
The north-facing shore of the spit truncates the gravel ridges, indicating longterm retreat. This shore is exposed to higher wave energy, and lacks a longshore sediment source. The backbeach in this area forms an overtopping ridge, or accumulation of gravel that is periodically overtopped by storm waves. The overtopping does not form distinct channels, so a landward-dipping slipface exists on the entire length of the ridge. Since the ridge is composed of flat pebbles, and currents during overtopping are primarily unidirectional, the internal geometry of the ridge is dominated by seaward-dipping imbricated pebbles.

The occurrence of accumulative ridges or overtopping ridges in the backshore corresponds to longterm shoreline changes. Since 1847, the north face has retreated at 15 cm/year, while the south face has advanced at 10 cm/year. Therefore, this landform is mobile and is migrating in a southerly direction. This mobility has been noted on other cuspate spits in the harbor, such as Bass Point, Long Island.

The spit encloses a small salt marsh system. The connection of the marsh with salt water is through an overwash channel. Since ridge growth is the response of intertidal gravel to most wave activity, the channel has only opened 3-4 times/year for the past three years. The brackish conditions presently in the salt marsh has lead to an active Phragmites sp. population overlying Spartina peat.

FIGURE 4

CROSS SECTION
NORTH SPIT, THOMPSON ISLAND



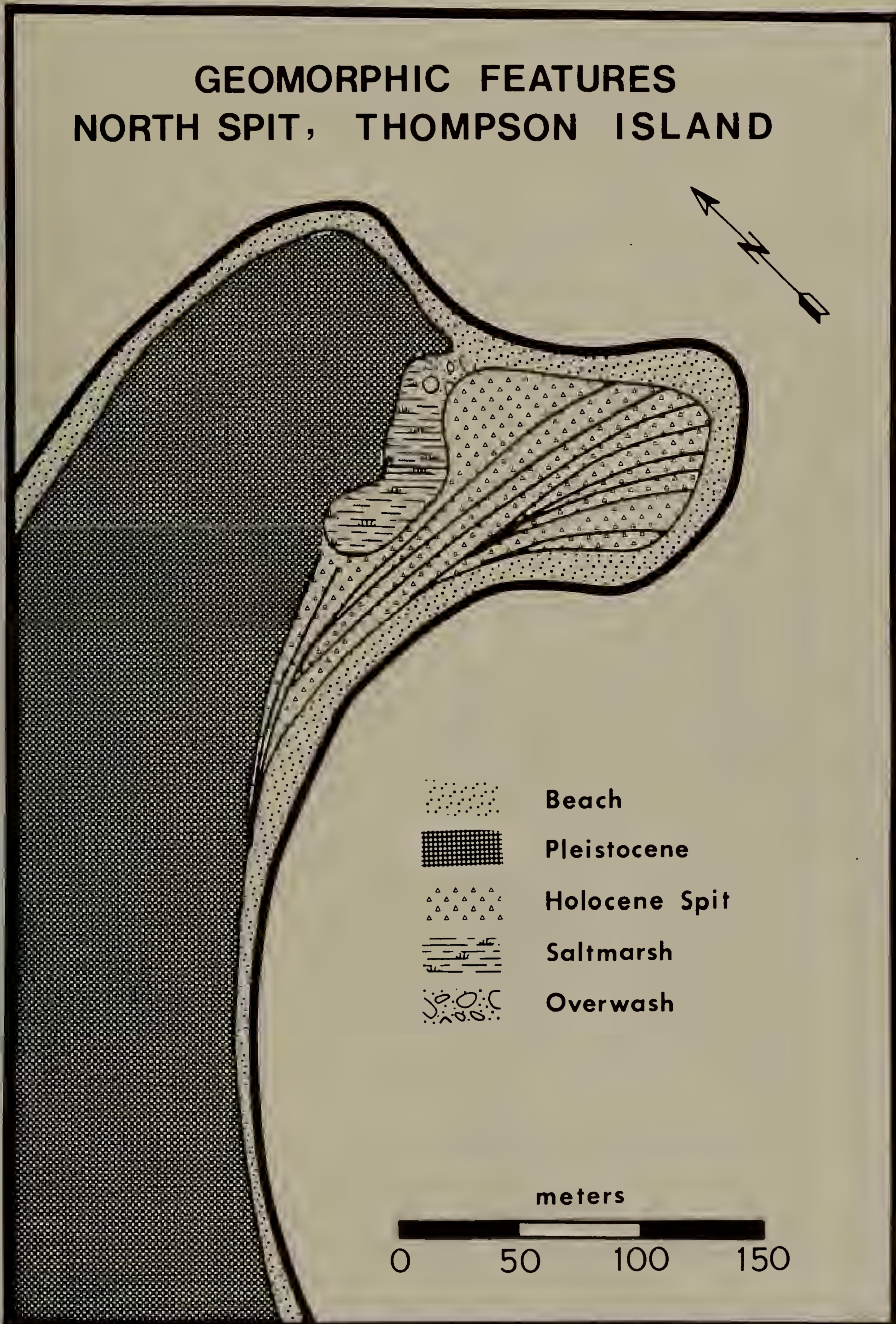

GEOMORPHIC FEATURES
NORTH SPIT, THOMPSON ISLAND
N
Beach
Pleistocene
Holocene Spit
Saltmarsh
Overwash
meters
0
50
100
150

FIGURE 5

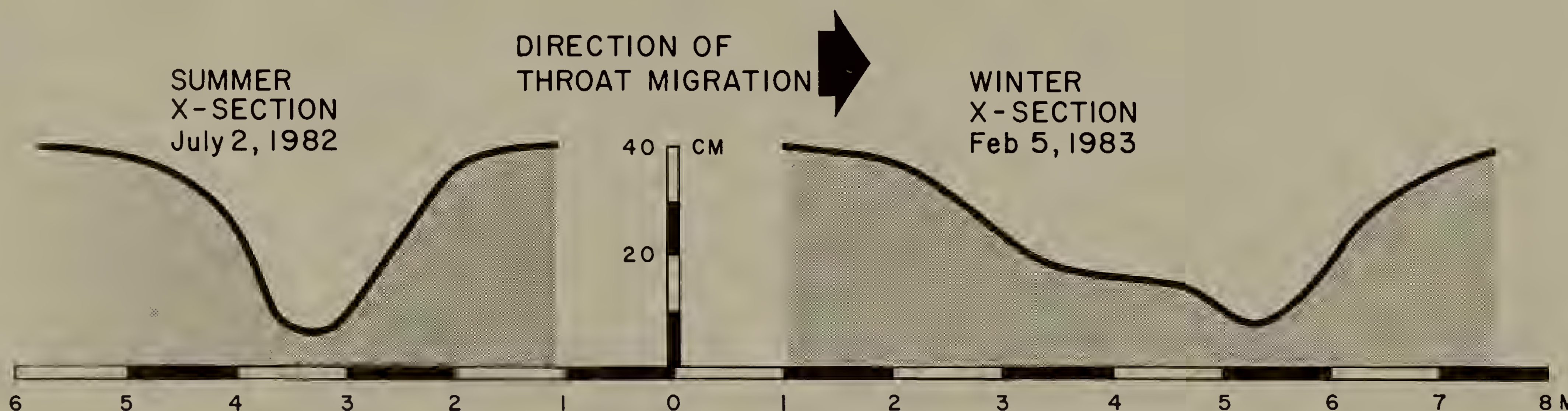
Soundings in the marsh show a maximum depth of about 3 meters (Figure 4). A steep slope exists at the boundary between the marsh and the first ridge of the enclosing spit. This steep slope is comparable to the present form of the downdrift end of the South Longshore Spit. The South Longshore Spit is probably an analog of the initial form of this spit.

Throughout the saltmarsh are several random cobble deposits resulting from winter sediment transport by ice. Freezeup around the island is not uncommon due to the low wave energy. The high tide range causes continual floating and grounding of shore ice while freezing is taking place. This is effective for entrainment of beach materials into the ice. Since freezeup is not usually complete throughout the harbor, waves continually redistribute the shore ice. This has resulted in ice accumulations up to 1.7 meters in height around the spit. However, gravel ice-push ridges have not been observed. This may be due to the continual wave action and large tide range. The ice foot is always fractured, due to tidal flexing, and can more readily be pushed landward by storm wave action. Although shore-ice forms are large, beach profiles before and after freezeup in 1981 on the south shore of the spit showed no measureable change in the beach. The major impact of ice on this shoreline is the redistribution of saltmarsh peat. The ice-transported peat blocks have established a fringe marsh along much of the eastern shore of the island.

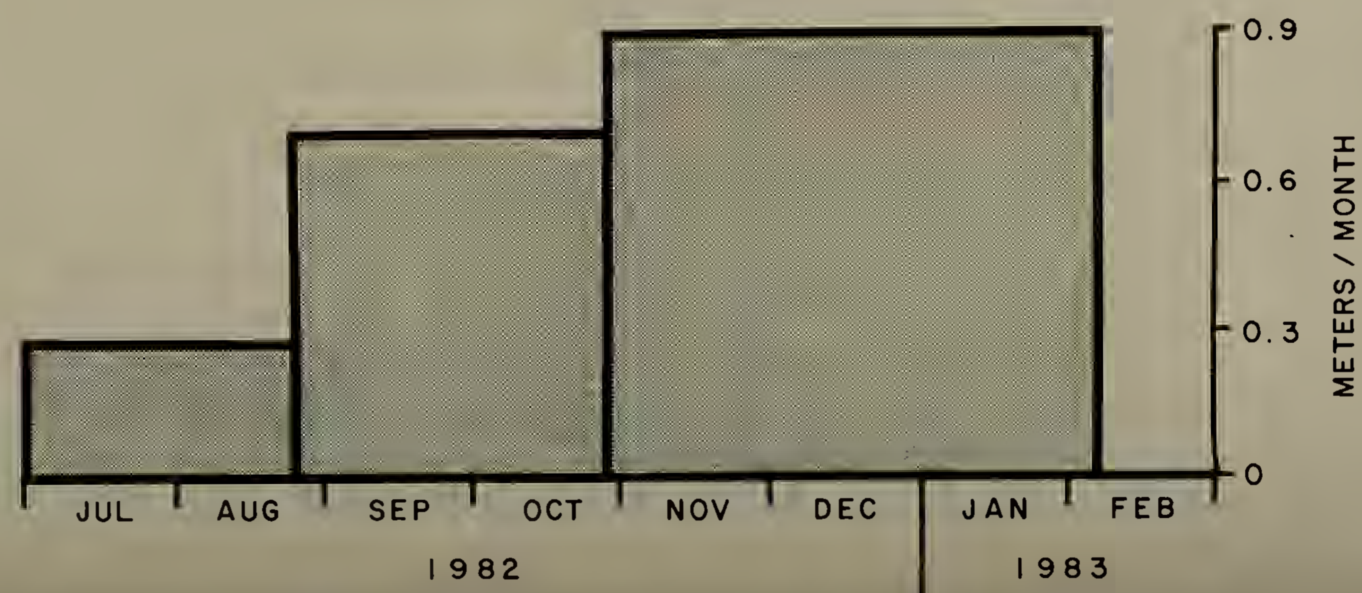
The south face of the North Cuspate Spit is an unobstructed length of beach with a known net longshore drift direction (north). Sampling of sediments at both the low water line and storm ridge crest have provided an indication of longshore sorting of gravel by low wave energy. Preliminary data indicates an increase in length, a decrease in sphericity, and more negative OP index in the direction of net transport. This suggests that larger, flatter, and more disc-like particles are preferentially moved alongshore by waves. Observations of tracers have indicated that this preferential transport is not due to an increased efficiency once the particle is initiated. They are too large for intermittant suspension in this wave environment and their pivotability is extremely low, so that they cannot efficiently roll in the swash zone. Deployment of tracers for 3-6 tide cycles during non-storm conditions showed that spherical shapes consistantly moved farthest. However, the majority of pebbles (over 90%) that moved at all were discoid. These trends occured when tracers were placed in a low mound. If the tracers were placed one pebble thick over a sandy gravel substrate, virtually no movement was ovserved.

These preliminary studies indicate that in low energy settings, the high porosity of a pebble substrate plays a significant role in initiation. Increased pore pressure near the plunge point of the wave can initiate motion. Spherical shapes had minimal resisting area to substrate pressure surges relative to their mass, and tend to be locked into a fixed position in the rough bed. While initiation is more difficult, they are readily transported by rolling once motion begins. Flat shapes have larger resisting areas to substrate pressure surges relative to their mass, and are not locked into a fixed position in the rough bed.

FIGURE 6 OVERWASH THROAT FORM



OVERWASH THROAT MIGRATION RATE



They are readily initiated, but movement per initiation is only a few millimeters.

Since the longterm trend shows larger, flatter particles are found farther downdrift, the controlling transport mechanism appears to be the preferential initiation of flatter particles.

South Longshore Spit

The South Longshore Spit differs from the other spits on the island and most spits in the harbor in that it does not represent a regional drift convergence point. This is due to the sheltering from the east by South Cuspate Spit. The longshore sediment source has been cut off for the past few decades by a tidal inlet updrift of the spit (Figures 2 and 3).

The spit is composed of two geomorphically distinct regions. The updrift end of the spit has existed prior to 1770. This portion of the spit is fully emergent. The supratidal areas are composed of flat pebbles forming a continuous overtopping ridge. This updrift region borders on a narrow saltmarsh, and is close to welding onto the adjacent shoreline. The landward migration rates between 1982 and 1984 have averaged 4.6 meters/year. This rate is probably influenced by the lack of a longshore sediment source.

A gravel overwash throat has existed on this portion of the spit since at least 1978, and may have opened as a result of the February 9, 1978 nor'easter (Blizzard of '78). The processes associated with this overwash system differ greatly from overwash on sandy barriers. The overwash channel is a semi-permanent feature, and migrates in the downdrift direction similar to a tidal inlet. Migration rates increase in winter months, and have averaged 7.5 meters/year between 1981 and 1984. The cross-sectional area of the throat also increases during winter months, presumably due to larger volumes of overwash flow (Figure 6). The migration of the throat has lead to the deposition of a 30 meter long fan/platform overlying the adjacent saltmarsh.

Overwash is not primarily a storm event. The maximum throat elevation is typically near mean high water. Most tides above that level, or neap tides during higher wave energy events, do overwash. Accumulative gravel ridges regularly migrate up the beachface and block the throat, but are readily breached by seepage (q.v) and runup.

Sediment transport during overwash is driven by wave bores entering the throat and downslope flow of water. Wave bores have not been observed to be effective at initiation without accompanying flow. Since there is a lag of about ½ hour in the filling of the marsh (by way of the lagoon) during rising tides, water levels are higher on the seaward side. The first stage of overwash is seepage through the barrier. The elevation of the backbarrier is about 10-15 cm higher updrift of the throat as compared to downdrift areas due to prior deposition of the fan/platform. Seepage was consistantly first observed adjacent to, and downdrift of the throat position. While the volume of water that entered the marsh as seepage was not significant in filling the marsh basin, it attained sufficient velocities to winnow and transport sand from the gravel ridge and deposit seepage lobes landward of the ridge slipface.

The flow through the overwash throat took place from ½ hour before high tide, and ended at high tide. By high tide, the marsh basin had filled so water no longer flowed through the throat. Overwash flow and accompanying wave bores transported all sizes of material through the throat. Transport across the fan/platform was dominated by down-gradient flow. While coarse material tended to move landward, sand-sized material accumulated as levees on the channel margins. The levees were best developed when wave action was low (which was most typical). As water levels increased on the fan/platform, the levees consistantly were first overtopped and breached at the same position: the downdrift side of the throat, which is adjacent to the saltmarsh surface. This area had the steepest gradient as the existing fan/platform raised basin elevations both landward and updrift of the throat position. Once a crevasse formed in the levee, some flow was diverted from the existing landward-oriented channel. A microdelta composed entirely of sand encroached laterally on the marsh, while all transport of coarser material was landward. The wave bore moving landward through the throat apparently played a significant role in the initiation and transportation of coarser material. The area of sand deposition through the levee crevasse is the same area that sand seepage lobes were deposited earlier in the event. In future overwashes, the throat will migrate downdrift and the cobble layer will be deposited over the sand.

The characteristic depositional unit resulting from this gravel overwash is a reverse graded, gravel-over-sand sequence. The gravel layer may show faint coarse/fine layering. This probably represents wave setup, which causes high velocity surges through the throat with 2-5 minute periods. The sandy levees were not found preserved in the sequence.

The downdrift end of the South Longshore Spit may have accreted since 1893, as it is not shown on a survey of that date. It is covered during normal high tides (therefore, technically it's a bar), although its crest elevation is typically near mean high water. This portion of the spit has retreated at an average rate of 0.48 meters/year between 1982 and 1984. Since this gravel spit/bar does not support dune grasses, nor is there any aeolian transport, a mechanism for emergence of this feature above mean high water is not obvious. Most of the length of this downdrift segment of the spit does not border on saltmarsh, as does the updrift segment. The downdrift segment encloses a small lagoon comprised of subtidal muds.

One position on the downdrift end of the spit is regularly emergent above mean high water (Figure 7). The emergent gravel "hump" is adjacent to an isolated marsh clump in the lagoon. The emergent hump was up to 15 cm higher in the spring and summer when Spartina grasses behind it were tall, and lower or non-existant in the winter when grasses were not present.

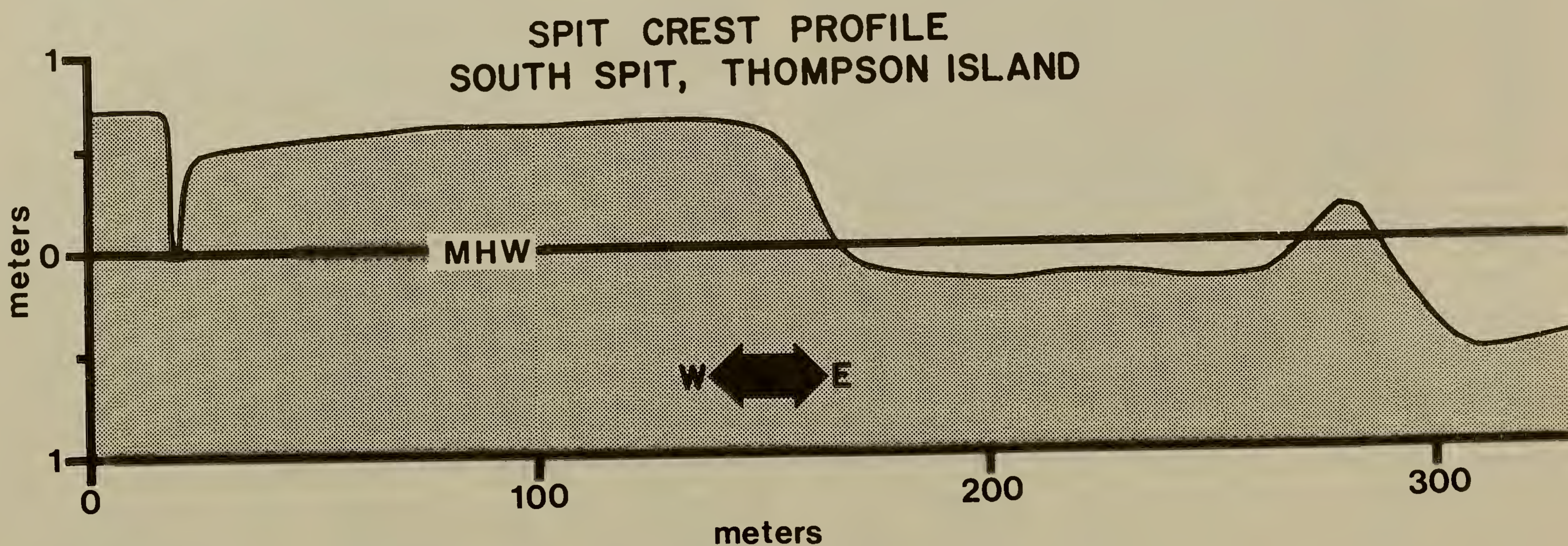


FIGURE 7. Profile along crest of South Longshore Spit

Since the emergent updrift segment of the spit ends abruptly where the adjacent marsh ends, and the hump location corresponds to the presence of lagoonal saltmarsh, the saltmarsh appears to be a controlling factor in gravel spit emergence.

The landward side of the downdrift spit/bar was composed of a continuous 2½-3 meter high slipface. The dip of this slipface was most typically 25-32°. This large, steep face played a role in a sediment transport process resulting from ripples (ht = 2-8 cm) formed in the lagoon. West to southwest winds in the lagoon generated ripples that broke on the spit/bar slipface. The result was downslope transport of sediments in the swash zone of the breaking ripples. During rising tides, this samll-scale erosional scarp migrated up the slipface as water rose. During falling tides, erosion and downslope transport due to ripple swash created a small, lower slope (10-20°) platform below the ripple plunge point. As the tide fell, the ripple swash zone moved down to this lower slope platform and little transport took place. A further fall in water level placed the ripple swash zone on a higher slope again, and the process was repeated. The result at low tide was a series of micro-scarps and micro-ridges extending down the slipface of the spit. Theses "water-level lines" typically had a vertical spacing of about 10 cm.

The formation of water-level lines played a role in the downslope transport of sediment on the landward, steep spit/bar slipface regardless of the approach angle of the ripples. The processes associated with water-level lines also apparently play a significant role in the longshore transport of sediment on the landward side of the spit/bar. Due to the short period ($\approx$ 1 sec), short wavelength ($\approx$ 10 cm) of the incoming ripples and steep nearshore gradient ($\approx$ 30°), the ripples do not refract as they approached shore. As the prevalent southwest wind direction aligns with the long axis of the spit/bar, ripples often approached nearly perpendicular to the shore (Figure 8). During high wind events, a wave bore was established along the shore (similar to face-travel of waves on a vertical seawall). Longshore currents have been recorded up to 40 cm/sec. Extremely high rates of drift occur in the small area of the ripple swash zone. This transport does play a measureable role in the form of the spit, as the downdrift tip periodically recurves into the lagoon due to normal wave refraction. Following periods of intense southwest winds, the recurve is eroded and planed-off from the landward side of the spit. If the longterm role of water-level line processes is comparable to short term observations, then the position and form of the South Longshore Spit results from a drift convergence

Acknowledgments

The support and cooperation of Thompson Island Education Foundation is gratefully acknowledged. The assistance of Kenneth Leach, Marcia Berman, and Ernest Waterman is appreciated.

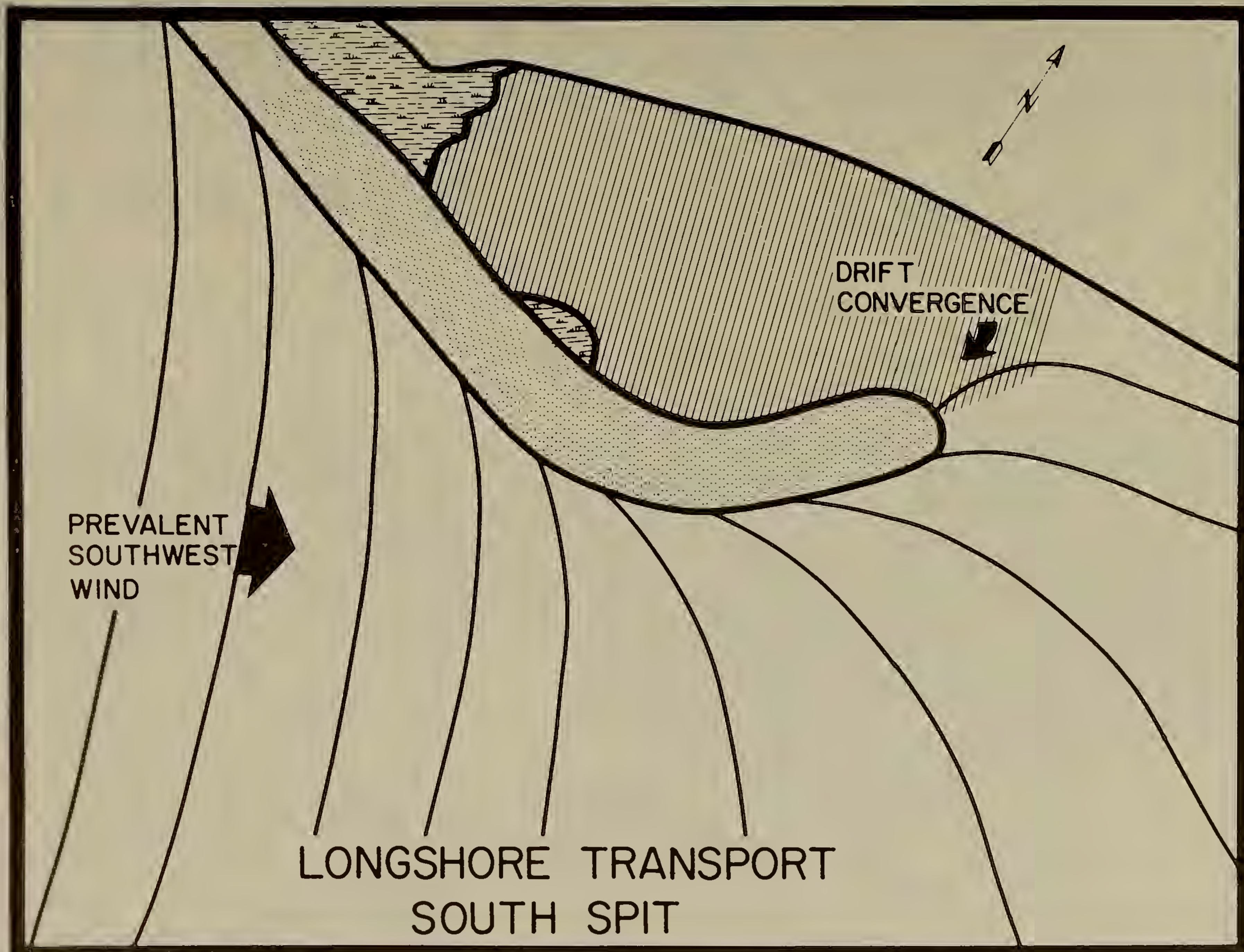


FIGURE 8. Longshore drift by ripples inside lagoon converges with regional waves at spit tip

HAZARDOUS WASTE PROBLEM SITES

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Introduction

Love Canal. Virtually overnight, engineer William Love's ill-fated attempt to construct a navigable power canal between branches of the Niagara River became synonomous with hazardous waste. Within a matter of months, the discovery of other major sites in Grey, Maine; Lowell, Massachusetts (Silresim); and West Point, Kentucky ("Valley of the Drums"), catapulted the question of how industries dispose of their wastes from the purview of a few regulatory agencies into the public eye. Sunday supplements, made-for-TV movies, and even comic strips all reflected the country's heightened concern with the real, potential, or imagined threats to public health and safety which chemical wastes - and, by extension, the companies which produced these wastes - represented.

Out of this explosion of hazardous waste issues into the public consciousness was born the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Among its other provisions, CERCLA provided for the creation of a fund to be used by the federal government to clean up "uncontrolled" hazardous waste sites, sites where the parties responsible for the problem were unwilling or unable to pay for the clean-up. This fund, the "Superfund," is allocated to various sites across the country in accordance with a complicated ranking and selection system.

With its long heritage of such industries as tanning and metal plating, and its high concentration of high-tech firms which generate large volumes of a variety of spent solvents and similar wastes, it is no surprise that New England has its share of superfund hazardous waste sites. In southern New England, their occurrence is directly related to the proximity of the manufacturing facilities. In northern New England, the smaller number of industries is compensated for by the greater amount of open, isolated land in which to illicitly dispose of hazardous wastes.

This field trip will visit two or three hazardous waste sites in northern Massachusetts and/or southern New Hampshire. In selecting possible sites for this field trip, the trip leaders have had to consider such disparate items as location, significance of geology to overall site conditions, accessibility, the need for personal safety precautions (i.e., disposable coveralls, respirators), and the status of pending litigation. Due to the general sensitivity of industries to being identified as hazardous waste sites to busloads of strangers, only uncontrolled sites were considered. Unfortunately, it is not possible to predict in July which sites will be available for visiting in the fall. This decision will be made in late